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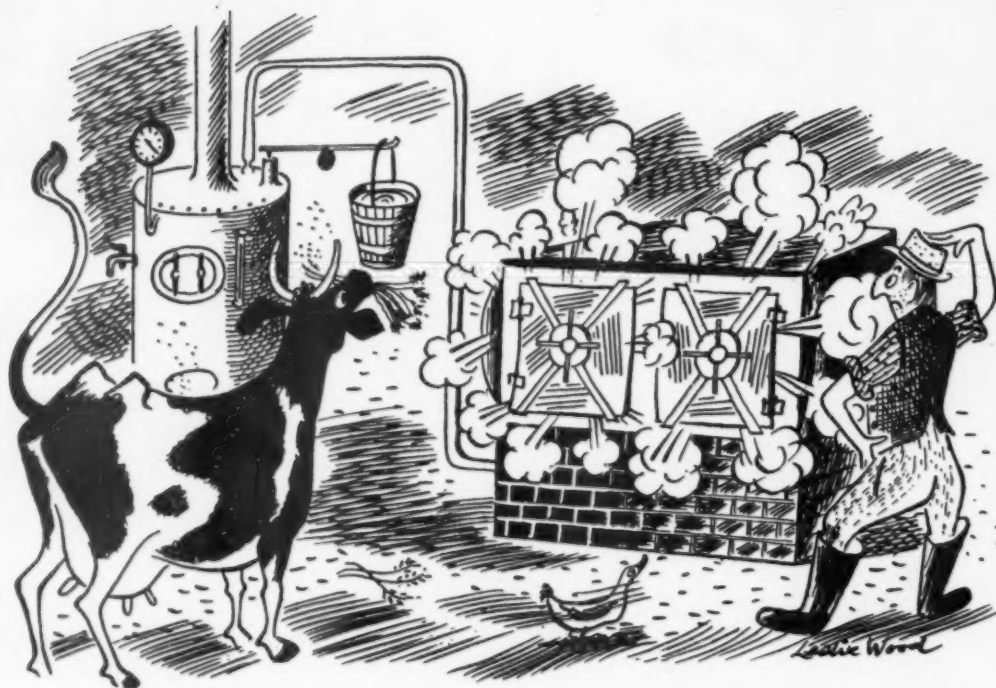
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*Photograph approximately full size by courtesy of Joseph Lucas Ltd.

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Other uses for the transport industry

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Speed of production is an outstanding feature of the die casting process — the shortest distance between raw material and finished product. Zinc alloys are the most widely used of all metals for die casting because they yield castings with the following qualities :

STRENGTH : Good mechanical properties for stressed components.

ACCURACY : Castings can be made practically to finished dimensions and need little or no machining.

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These are the properties which accounted for the widespread wartime use of zinc alloy die casting in the quantity production of such things as fuses, gun sights, periscopes and tank carburettors.

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Alloys conforming to B.S. 1004 should be specified for all applications where strength, accuracy and stability are essential.

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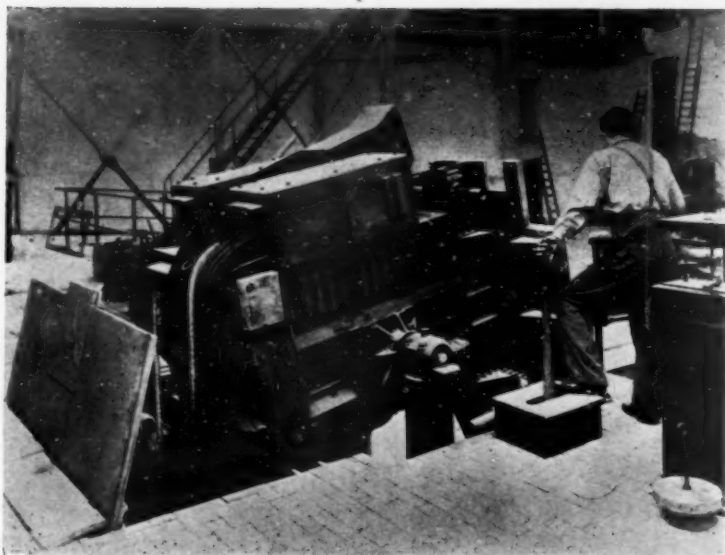
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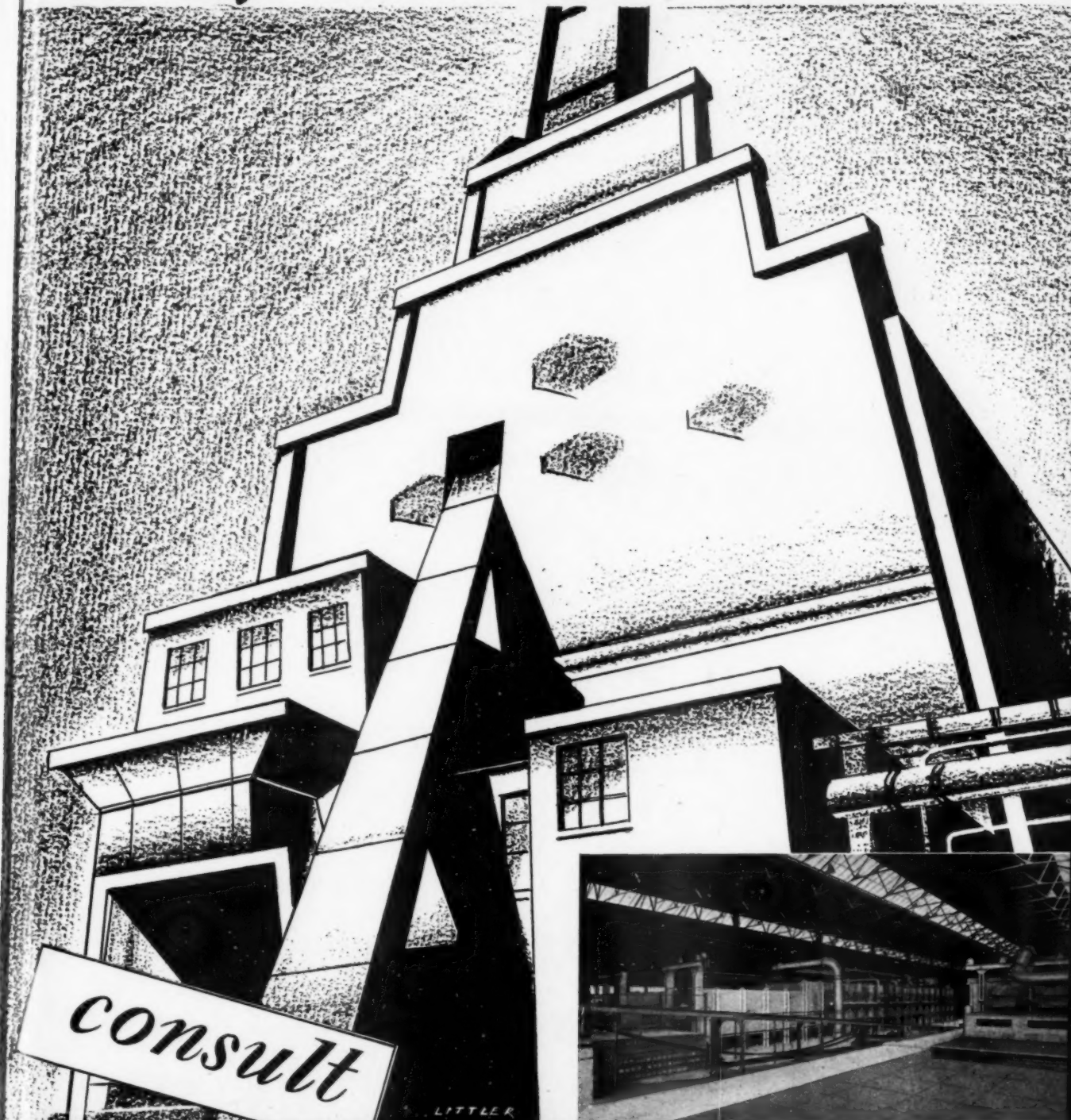
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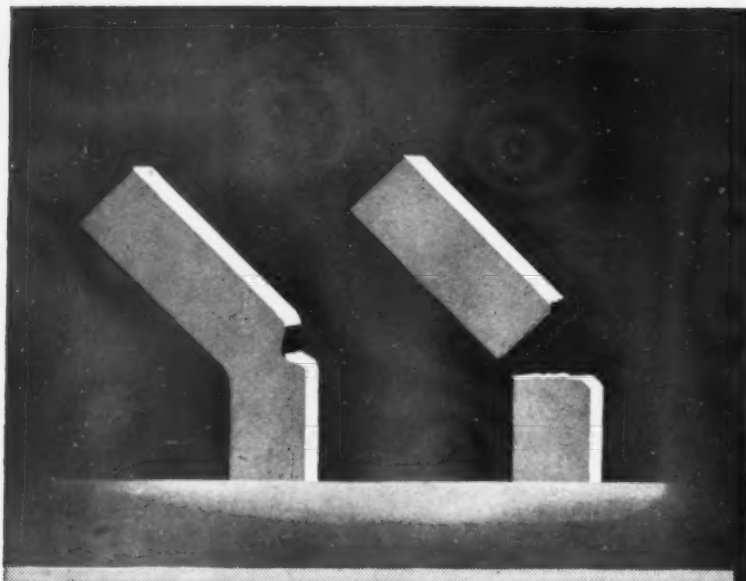
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As far as tensile properties went, the two steels were identical. But impact testing showed a fatal difference—one was temper brittle.

Molybdenum is a standard remedy for temper brittleness. Parts made from molybdenum steels are protected from unexpected failure, not only from impact loads but from overloads likely to develop instantaneous peaks.

The subject of molybdenum's effect on temper brittleness and its value to the user of steel is discussed at length in our technical book which is yours for the asking.
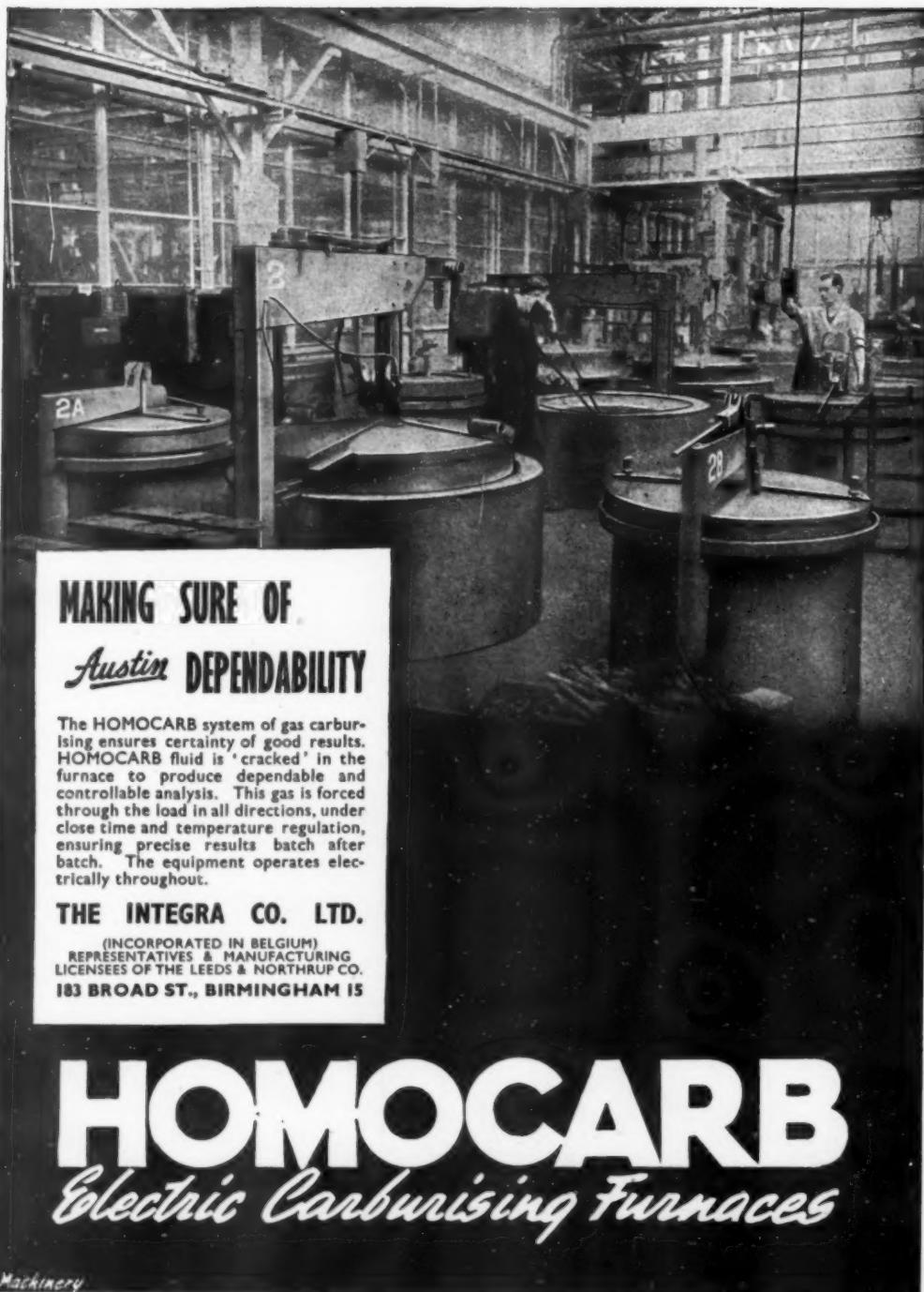
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PRINCIPAL CONTENTS IN THIS ISSUE:

The articles in this Journal are indexed in *The Industrial Arts Index*

HALE AND HALE (TIPTON) LTD.
Expanding Output

The twelfth annual general meeting of Hale and Hale (Tipton), Ltd. was held on Dec. 17th, 1948, at Dudley, Mr. W. Edgar Hale, M.I.-Mech.E., M.Inst.F., the chairman, presiding.

The following is an extract from the Chairman's review which was circulated with the report and accounts :—

The profit and loss account shows a trading profit of £43,815, to which is added dividends received from the two subsidiaries in respect of the period from April 1st, 1947, to August 4th, 1947, amounting to £12,903, and other investment income of £555, totalling £57,273. In this connection the dividends from the subsidiaries are the first and only dividends paid and are in respect of the period ended August 4th, 1947, but it has not been deemed advisable to declare any further dividends from these subsidiaries for the current year, in view of the parent company's policy of stabilising its Ordinary dividend to conform with the wishes of the Chancellor of the Exchequer. From the total of £57,273 have been deducted directors' and auditors' fees, and depreciation, amounting to £6,907, and taxation £24,961, leaving a net profit for the year of £25,405, which compares with £18,902 the net profit for last year, an increase of £6,500. Full provision has been made in the accounts for the company's liabilities to profit tax and income-tax which will be assessed by reference to the profit for the year ended August 4th, 1948.

Dividend 20 Per Cent

To the balance brought forward of £13,936 has been added the net profit for the year of £25,405, making a total of £39,341, out of which have been paid the Preference dividends for the year ended June 30th, 1948, amounting to £3,025, and the interim dividend of 5 per cent. on the Ordinary shares taking £2,750. Your directors now propose the payment of a final dividend on the Ordinary shares of 15 per cent., less tax, making 20 per cent. for the year, and that an amount of £2,500 be transferred to reserve account for contingent obsolence of buildings, plant and machinery, and £10,000 to general reserve, leaving a carry-forward of £12,816.

You will observe from the balance-sheet that fixed assets stand at £175,281 as compared with last year's figure of £162,111. This increase is brought about by the acquisition of further shares in the subsidiaries to make the company's holding complete with the exception of one share only in each of the subsidiary companies, and further expenditure on plant and equipment, less, of course, the provision for depreciation during the year. Current assets total £144,069, and compare with last year's figure of £128,815. On the other side of the balance-sheet it is noteworthy that capital and surplus now amount to £303,816 and current liabilities total £82,693. I think you will agree that the liquid position is very sound.

Production and Sales

Our production of " fine Blackheart malleable iron castings " is acclaimed by users as being unequalled in quality, and it is backed by a service of such advanced character as would, a few years ago, have been regarded as impossible of achievement in foundry practice. It will be of interest to you to know that our customers embrace most of the distinguished enterprises engaged in every branch of the engineering world, producing an infinite variety of manufactured articles, such as heavy commercial vehicles, private motor-cars for export, tractors, agricultural machines of every description, railway equipment and mining and heavy electrical plant, so that you will appreciate that it is a very comprehensive engineering sphere for which we cater. The demand for our Blackheart malleable iron steadily increases.

Over the past nine or twelve months there has been an appreciable increase in our sales turnover and tonnage output, and, although we are still unable to meet fully the demands which are being made upon us, every avenue is being explored to increase our output still further. Since November, 1947, we have not made any general increase in our selling price, as it is the company's policy to maintain present price standards as long as economically possible.

We feel, however, that, apart from ourselves and similar suppliers being

desirous of stabilising prices, more should and could be done by the appropriate authorities to stabilise labour costs and the costs of basic materials upon which final prices depend. In the matter of exports, the maintenance of which, at high level, is so important at the present time, it is impossible, due to our position as raw material suppliers, to indicate precisely the proportion of our output which is destined for abroad, but in-so-far as we are able to judge, the figure would appear to be in excess of 80 per cent.

Subsidiaries

Of our subsidiary, Chatwins, Ltd., it is my pleasure to report that their very distinguished line of solid fuel appliances, including grates, ranges, domestic boilers, free standing cookers, etc., sold under the trade names of " Sunbeam," " Sunbeamette " and " Prefect," are in most excellent demand, both for individual users, and particularly for the numerous municipal housing schemes. The design, quality, manufacture and finish are of the highest possible standard, and the size of the company's order book proves beyond any question of doubt that this view is shared by a large volume of the discerning public.

J. and J. Whitehouse (Tipton), Ltd., our other subsidiary, is engaged in the manufacture of a great variety of cast-iron hollow-ware, almost the whole of whose product is destined for abroad, mostly for tropical countries, and their order book proves that the company's productions are regarded in much favour by consumers overseas.

There has been every effort made by all concerned to understand and co-operate with each other, resulting in splendid team work in the foundries which is a credit to all. We owe a very great debt of gratitude to everyone associated with the company, executives and workpeople alike, as well with the holding company as its subsidiaries — Chatwins, Ltd., and J. and J. Whitehouse (Tipton), Ltd.—and I would like to take this early opportunity of saying how much their efforts are appreciated.

The report and accounts were adopted.

German Steel

AT a time when European reconstruction needs steel, German steel plants are being dismantled. It has been asserted that this dismantling is being carried out in the interests of European recovery as a whole ; that the object is to transfer the dismantled equipment to other places where it can be utilised more speedily than in Germany and to greater advantage in European reconstruction. In some cases advantages will probably result, particularly in some small manufacturing plants concerned primarily with finishing, but, for the larger steel plants, there can be no doubt that, from an economic point of view, their removal can only delay recovery. Consider, for example, the dismantling and reconstruction of a large sheet mill. The work involved would occupy about a couple of years during which there would be no production from the mill. Even after its reconstruction some time must elapse before such a plant could reach its production capacity. But steel is in demand now and efforts should be made to give reasonable facilities to Germany to play her part in the recovery programme.

Although there has been a changed outlook concerning the control of German industry, particularly in steel production, continued dismantling of major and ancilliary steel plant will seriously interfere with the German steel industry reaching the production target set by Allied control. In 1947, when a low level of production was emphasised, steel production was 2·9 million tons. Following criticisms on the low level of production orders were issued early in 1948 for the speeding up of steel production. A mixed commission was to be set up to investigate the position and develop plans for increased production, but the commission was dissolved before its activities matured. The industry was instructed to raise steel production to the 6 million ton level at a time when ingot production was on a 3·5 million ton level. There were many obstacles retarding the achievement of such a target, notably supplies of raw materials which could only be obtained through the same authorities who issued the order for increased production. With the currency reform there was an upward swing ; absenteeism reached a minimum and output showed a substantial rise. Deliveries of solid fuel exceeded allocations ; ore, scrap and other raw materials were delivered in increasing quantities and production rose to such an extent that by August, 1948, the target figures of the 6 million ton plan were generally reached.

The needs of the European recovery have now led to a further revision of the programme, and the German steel industry has been set a production target of 10·7 million tons a year. It is apparent that Germany is now recognised as a member of the European community of nations, and is expected to make her contribution to the reconstruction and final recovery of Europe, but the Allied Control Authorities intend to prevent her industrial production from ever regaining strategical importance. With this in view, plants are being dismantled so that her industrial economy can be adjusted to this level. It is in determining the plants to be dismantled that economic and political influences conflict, which will undoubtedly interfere with German industry playing its full part in European recovery and also of becoming a valuable link in world economy.

Even on the larger issues concerned with the limitations of steel capacity there are divergences of opinion among the control authorities and German industry which have not yet been reconciled. A plant may be capable of producing to the full capacity for which it was designed, but only when other considerations are favourable. Dismantling of plant in addition to limiting capacity must also hamper production, because it interferes with the whole industrial life of the nation. There is, of course, much to be said for the dismantling of plants which were established solely for armament purposes, but the list of plants being or to be dismantled indicates the industry is likely to lose the greater part of its competitive strength. Surely there are inconsistencies in an arrangement which makes favourable concessions to the industry in fixing ingot-steel production and also includes a dismantling plan without regard to economic integration.

The authorisation to produce 10·7 million tons of ingot steel should be accompanied by the provision of adequate available plant and by a proper combination of facilities affording subsequent mechanical treatment. A common object should be aimed at in determining production capacities. In determining blast-furnace capacities, for instance, some freedom in range should be given the industry to work out most suitable burdens to make the best possible use of the lean domestic ores, using high-grade imported ores only to an extent likely to provide the best productive conditions. In the case of steel plants it should be possible to make proper allowance for repairs since the general deterioration of working conditions means that repairs now occupy more time. This applies especially to basic converters and to open-hearth furnaces, some of which, now on the dismantling list, should be retained in the German industry to enable it to maintain the level of production authorised.

On the question of grades of steel produced it is noteworthy that facilities are to be left to the industry to permit 2·8% of production in electric steel. This is a very low proportion, and the industry is justified in expecting that facilities will be granted to bring the proportion of electric steel to total ingot tonnage more into line with the proportions customary in other countries. An adequate quantity of electric steel should be available as well as appropriate rolling mill, forge and drawing equipment, for tools, ball bearings, high-grade implements and machines. Otherwise there will be a shortage of high-grade machining and measuring tools

for the processing industries. Machining costs will rise with a decrease in quality and increased operating periods, which would impede production and retard recovery.

It is true that, after two German aggressions, distrust will continue to exist, but if the European Recovery Programme is to be successful an improvement in the relations with the German people should be sought. Germany can, of course, do much to remove uncertainty and suspicion, but it would help towards a better understanding if she were given a reasonable opportunity to restore her economy. This could be done by assisting the steel industry, which is vital to her economy, by favourable reconsideration of the plant-dismantling list, with a view to permitting the new production target to be reached. It is in making Germany a partner in the struggle to effect European economic recovery that the best hopes for the future lies.

Capper Pass Awards

IN 1947, the Directors of Messrs. Capper Pass & Son, Ltd., Bristol, sharing the regret which had been expressed in many quarters at the dearth of papers on processes and plant used in extraction metallurgy in the *Transactions of the Institution of Mining and Metallurgy*, and of papers on processes and plant used in the fabrication of non-ferrous metals in the *Journal of the Institute of Metals*, offered to these Institutions the sum of £200 per annum for a period of seven years to be applied as follows :—

  (*a*) £100 per annum to be available for one or more Awards to the authors of papers on some aspect of non-ferrous extraction metallurgy ;
  (*b*) £100 per annum to be available for one or more Awards to the authors of papers relating to some process or plant used in the extraction or fabrication of non-ferrous metals.

Authors should be persons engaged full time in industry or practice.

The Councils of the Institution of Mining and Metallurgy and of the Institute of Metals gratefully accepted this offer, and appointed a joint adjudicating committee. This committee has power to make the awards on behalf of the two societies and may, at its discretion, make no award or awards of less than the money available if, in its opinion, the quality or number of papers submitted in any year fails to reach a suitable standard. Any sums not awarded will be carried forward to future years.

The Councils of the Institution of Mining and Metallurgy and of the Institute of Metals hope that the generous offer made by Messrs. Capper Pass & Son, Ltd., will stimulate the writing of many papers of the types for which the Awards are to be made. Papers on extraction metallurgy should preferably be submitted to the Institution of Mining and Metallurgy, while those on processes and plant used in the fabrication of non-ferrous metals should preferably be offered to the Institute of Metals. Both societies are prepared to accept papers of suitable quality from non-members.

Authors should note that applications should not be addressed to the Adjudicating Committee requesting that their papers should be considered for an Award. All papers published by both societies will be examined by the committee annually, and notices of the Awards will be published in the journals of the two societies and in the Press. The committee will shortly consider all papers published by the two societies during 1948.

New Year Honours' List

In the New Year Honours' List, published as a supplement to the *London Gazette*, a number of scientists, industrialists and technicians were honoured, amongst them the following :—

Knight.—J. H. GODDARD, Esq., President, Machine Tool Trades Association. H. L. GUY, Esq., Chairman of the Mechanical Engineering Research Organisation, Department of Scientific and Industrial Research, Secretary, Institution of Mechanical Engineers. D. MACLEAN SKIFFINGTON, Esq., Director, John Brown & Co., Ltd., Clydebank.

K.G.C.B.—SIR HENRY TIZARD, Chairman, Defence Research Policy Committee, Ministry of Defence.

K.C.B.—COLONEL P. G. J. GUETERBOCK.

C.B.E.—A. BLAIR, Esq., Engineer Manager and Director, Harland & Wolff, Ltd., Belfast. COL. W. C. DEVEREUX, Managing Director, Almin, Ltd. ; Chairman, International Alloys, Ltd. J. A. MILNE, Esq., Chairman and Managing Director, J. Samuel White & Co., Ltd., Cowes. J. MITCHELL, Esq., Managing Director, Iron and Steel Production, Stewarts & Lloyds, Ltd. Professor W. WARDLAW, Scientific Adviser to the Appointments Department, Ministry of Labour and National Service.

O.B.E.—Capt. J. J. C. ALLEN, Governing Director, John Allen & Sons (Oxford), Ltd. H. C. HALL, Esq., Metallurgical Research Consultant to Rolls Royce, Ltd. H. LITHGOW, Esq., Shipyard Manager, Swan Hunter and Wigham Richardson, Ltd., Wallsend-on-Tyne. P. H. PETTIFORD, Esq., Deputy Superintendent, Royal Mint. G. MACFARLAN SISSON, Esq., General Manager, Optical Works, Sir Howard Grubb Parsons & Co., Ltd., Newcastle-on-Tyne. J. WRIGHT, Esq., Director and General Manager, Dunlop Rim and Wheel Co., Ltd., Coventry.

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The Influence of Various Factors on the Creep of Lead Alloys

By J. Neill Greenwood, D.Sc., M.Met.E.* and J. H. Cole, M.Sc.†

Results of some creep tests on a number of lead alloys are recorded. The experiments, which have been in progress more than ten years, are concerned with the influence of steady stress at 20° and at 50° C. on alloys containing respectively copper and silver, and also the influence of steady stress vibration and previous heat-treatment on alloys containing respectively 0·075% copper and 0·03% silver.

Introduction

IN a recent article[1] the authors recorded some results on long-time tests on a pure industrial lead. In the present paper it is proposed to record results on some creep tests of alloys made with this same lead, which have been in progress more than ten years. In work of this kind investigators are always conscious that they could have planned their experiments better if they had known in advance the kind of results they would obtain. Such foresight is, of course, not granted to many. In the present instance, in addition, the authors did not know that a prolonged period of war lay ahead and did not contemplate a period of over ten years elapsing before they would finally assess the results of the experiments. Neither had they grasped ten years ago the full significance of the various types of creep—and the phenomenon which they have called "creep yield." Consequently there are many gaps in their results. However, it is thought they may have some technological value, and that by publishing them they will contribute to the completion of a complex pattern in conjunction with the results of other investigators.

The experiments fall into three groups :—

(*a*) The influence of steady stress at 20° C. on alloys containing respectively copper and silver.

(*b*) The influence of steady stress at 50° C. on similar specimens.

(*c*) The influence of steady stress vibration and previous heat-treatment on alloys containing respectively 0·075% copper and 0·03% silver.

The experiments of group (*a*) were a continuation of those previously described, [2-4] whilst those of group (*b*) followed naturally using the same alloys. Those of groups (*c*) were complementary to and simultaneous with those reported in the previous article.[1]

Copper-Lead Alloys

Tests at 20° C.—Lead copper alloys containing 0·005–0·34% copper were made by dissolving in molten lead (batch U always used for these investigations) drillings of a mother alloy containing 0·75% copper. The alloys were cast into ingots 6 × 1 × 1 in. and were rolled to strip 1¼ × ⅛ in. under standard conditions. The crystal size varied from 1 mm. diameter for the pure lead

1 Greenwood, J. Neill, and Cole, J. H., *Metallurgia*, April, 1948, 285/289.
2 Greenwood, J. Neill, and Howard, K. Worner, *Proc. Aust., J.M. and Met.*, 104 (1936), 385.
3 Greenwood, J. Neill, and Orr, C. W., *Ibid*, 109 (1938), 1.
4 Greenwood, J. Neill, and Orr, C. W., *Ibid*, 112 (1938), 287.

to 0·1 mm. diameter for alloys containing 0·05% copper and over.

TABLE I.—PERCENTAGE EXTENSION OF COPPER LEADS
(Stress, 500 lb./sq. in. Temperature, 20° C.)

As rolled

Cu %	Duration (years)				Time to fracture and extension
	1	2	3†	5½	
0·0002 (U)	15·3	—	—	—	443 days, 27%
0·007	17·0	R*	—	—	592 ,, 32%
0·012	13·1	R	—	—	590 ,, 26%
0·066	0·85	1·6	2·2	3·5	
0·110	1·4	2·5	3·2	4·1	
0·34	1·7	2·8	3·6	4·8	

Annealed 100° C. for 15 minutes

0·0002 (U)	—	R	—	—	300 days, 25%
0·007	16·0	R	—	—	467 ,, 26%
0·012	14·2	R	—	—	612 ,, 31%
0·055	6·0	10·2	—	—	
0·066	1·6	2·5	2·8	3·8	
0·110	1·85	2·9	3·8	5·4	
0·34	3·4	5·4	6·8	9·6	

Annealed 125° C. for 24 hours

0·0002 (U)	14·9	—	—	—	496 days, 40%
0·007	17·8	—	—	—	421 ,, 20·5%
0·012	16·2	R	—	—	487 ,, 30%
0·055	8·3	15·3	—	—	
0·066	0·66	1·4	1·9	2·8	
0·110	3·1	4·9	6·5	9·6	
0·34	1·26	2·02	2·8	4·3	

* R means that the specimen recrystallised during the test.
† These values were obtained by interpolation.

TABLE II.—PERCENTAGE EXTENSION OF COPPER LEADS
(Stress, 350 lb./sq. in. Temperature, 20° C.)

As rolled

Cu %	Duration (years)				Average over 5½ years
	1	2	3†	5½	
0·0002 (U)	2·5	4·1	5·6	9·5	1·7%
0·007	3·8	7·8	—	—	—
0·012	3·5	7·1	11·5	—	—
0·066	0·07	0·14	0·25	0·6	0·1
0·110	0·14	0·31	0·4	1·0	0·18
0·34	0·23	0·45	0·65	1·02	0·18

Annealed 100° C. for 15 minutes

0·0002 (U)	2·3	3·8	5·0	7·7	1·4%
0·007	5·6	11·3	—	—	—
0·012	3·6	6·3	—	31·6	5·8
0·055	1·65	2·8	3·7	5·5	1·0
0·066	0·12	0·26	0·37	0·67	0·12
0·110	0·10	0·23	0·35	0·65	0·12
0·34	0·45	0·92	1·25	2·08	0·38

Annealed 125° C. for 24 hours

0·0002 (U)	2·65	5·2	7·6	—	—
0·007	2·65	7·2	—	—	—
0·012	2·45	4·9	—	—	—
0·055	2·5	4·1	5·6	8·4	1·5%
0·066	0·08	0·15	0·2	0·5	0·1
0·110	0·6	1·2	1·6	2·7*	0·5
0·34	0·06	0·14	0·24	0·47*	0·09

† By interpolation.
* The copper content of these two pieces was checked and they were found to be in correct order.

Creep tests were carried out in three conditions : (a) as rolled ; (b) annealed 100° C. for 15 min. ; (c) annealed 125° C. for 24 hours, and under two stresses, 500 lb./sq. in. and 350 lb./sq. in. The results after one and a half years' duration have already been published.[3] The results given in Tables I and II show the total creep in five and a half years.

Tests at 50° C.—All test pieces were prepared according to the standard practice previously described and were annealed at 100° C. for 15 minutes. Oven temperatures were controlled thermostatically at 49 ± 1° C. Duration was 300 days after which the pieces were left at ordinary temperature under load—equivalent initially to 350 lb./sq. in.—for a further eight years. For comparison, results previously obtained on the same alloys at 20° C. under similar stress and treatment conditions are given in Table III.

TABLE III.—PERCENTAGE EXTENSION OF COPPER LEADS
(Stress, 350 lb./sq. in. Temperature, 50° C.)

Annealed 100° C. for 15 minutes

| | Extension in 300 days (%) | | |
Cu %	50° C. (A)	20° C. (B)	Ratio A/B
0·0002 (U)	6·2	2·0	3·1
0·012	10·1[a]	3·1	3·3
0·055	8·9	1·4	6·4
0·066	1·6	0·11	14·5
0·110	1·8	0·08	22·5
0·34	4·0	0·4	10·0

[a] Recrystallised after 3·5% extension.

Simple values like those given in Table III can be quite misleading when the recrystallisation phenomenon occurs during the test. This is illustrated in Fig. 1 in the curves for the alloys containing 0·012 and 0·055% copper, respectively. It will be seen that the coarse-grained lower copper alloy (the lead is always coarse-grained after recrystallisation under stress) was creeping at a much lower rate than the fine-grained higher copper content lead. Consequently, after about 400 days the two curves would have crossed and the total elongation of the 0·055% copper lead would thereafter have been greater than that of the 0·012% copper lead.

In Table IV the extensions which occurred in eight years at ordinary temperature are given. These should be compared with the values in Table II with which in general they agree—with the notable exception of the 0·012% copper alloy, the low creep of which is due to the large-grain size following recrystallisation at 50° C.

Tests at 20° C. with superposed vibration.—In the previous article[1] a description was given of an arrangement for superposing a 50-cycle vibratory stress on the steady stress produced by direct load. The results given

Fig. 1.—Creep of copper lead alloys at 50° C. (120° F.) under stress of 350 lb./sq. in.
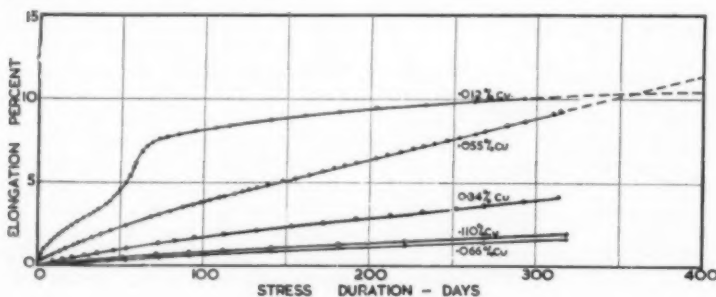
TABLE IV.—EXTENSION OF COPPER LEAD ALLOYS AT ORDINARY TEMPERATURE AFTER 300 DAYS AT 50° C.
(Stress, 350 lb./sq. in. Duration, 8 years)

Cu %	Previous extension at 50° C.	New extension at 20° C.	Rate of extension at 14/20° C. % per year
0·012	10·1	0·8[*]	0·1
0·055	8·9	8·0	1·0
0·066	1·6	0·03	0·004
0·110	1·8	0·7	0·09
0·34	4·0	1·5	0·19

[*] This had recrystallised in first period. The grain size had increased to 5 × 25 mm.

above confirm those previously obtained to show that maximum benefit from the addition of copper is only obtained if the eutectic proportion—namely, 0·06% is exceeded. Consequently for these experiments a new alloy was made containing 0·075% copper.

The alloy was cast and the strip prepared as previously described. However, in addition, an attempt was made to change the degree of dispersion of the copper in the alloy. This was done by subjecting the alloy to an intermediate anneal to allow the copper particles to coalesce. The ingot, after 25% reduction in thickness by rolling, was annealed for 40 hours at 250° C. It was then rolled to $\frac{1}{8}$ in. thickness by standard practice. The change in degree of dispersion of the copper particles was quite marked and was illustrated in the original paper.[3] This treatment is referred to as a " billet anneal." The test pieces whether rolled direct or after the intermediate anneal were annealed in two series : (a) 100° C. for 15 minutes, and (b) 125° C. for 24 hours.

TABLE V.—PERCENTAGE EXTENSION OF 0·075% COPPER LEAD ALLOYS

| Treatment | | Stress lb./sq. in. | With vibration | | Without vibration | |
			1 year	2 years	9 years	Rate/year
Rolled direct	:	250	0·06	0·11	0·4	0·035
100° C./15 min.	;	350	0·82	1·3	1·3	0·14
Billet anneal	:	100	0·18	0·23	0·1	0·01
100° C./15 min.	;	250	0·85	1·6	4·5	0·5
		350	6·7	15·7	Broke after 2½ years with further 47% ext.	
Rolled direct	:	250	0·12	0·18	0·25	0·03
125° C./24 hr.	;	350	0·86	1·4	1·3	0·14

The vibration was maintained for approximately two years and the test pieces then stood under stress for a further nine years. The results are given in Table V.

Fig. 2.—Comparison of rates of creep (total creep in one year) of pure lead and 0·075% copper lead under different stresses with superposed vibration (creep-yield curve) at 20° C. (68° F.).
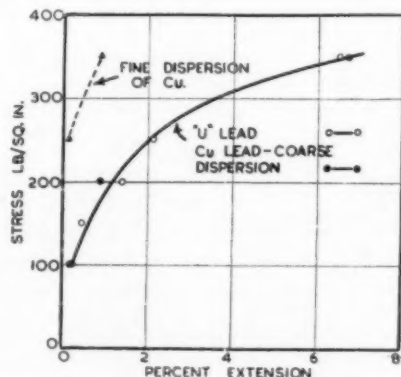
Summary of the Influence of Copper on the Creep of Lead

The results given in this article should be read in conjunction with those in a previous paper[3] to which they are supplementary.

1. Tests at ordinary temperatures under a stress of 350 lb./sq. in. extending over a period of years confirm the result that 0·06% of copper in lead decreases the creep rate by a factor of about ten. This is subject to the qualification that the copper must be highly dispersed.

2. At 50° C. this advantage is not so marked, the factor being reduced in general to about four. In other words, as the copper content increases the alloys appear to become more sensitive to temperature increase. This is shown in Table III where the ratio of extension at 50° C. to that at 20° C. is about three for the low copper leads and about ten to twenty for the higher copper leads.

3. As in the case of pure lead, the creep rate of copper lead is markedly increased by vibration. Comparison of Tables II and V shows that *under the stress conditions used* the creep rate was increased by a factor of about five to ten.

4. However, the copper lead (0·075% copper) maintained a considerable advantage over pure lead *under similar conditions of vibration and steady stress.* At 250 lb./sq. in. the copper lead has the advantage by a factor of about forty (*c.f.*, Table IV with Table V of reference 1). This advantage is not so great if the leads have been annealed at 125° C. for 24 hours—at 200 lb./sq. in., the factor under these circumstances being five.

5. The advantageous results of copper addition are lost completely if the copper is coarsely dispersed. Comparative values are given in Table VI and in Fig. 2, which also shows the extension in one year for the highly dispersed copper lead.

TABLE VI

Stress lb./sq. in.	Percentage elongation under vibratory conditions			
	U lead		Cu lead	
	1 year	2 years	1 year	2 years
100	0·2	0·35	0·18	0·23
200	1·4	2·8	0·85	1·6
350	6·5	9·2	6·7	13·7

It has been shown[5] that the solid solubility of copper in lead at 290° C. is very close to 0·005%. It is also known that copper forms a eutectic with lead at 0·06% copper content. It might be expected, therefore, that any eff-

Fig. 3.—Rate of creep of silver lead alloys under 350 lb./sq. in. stress, at 20° C. (68° F.). All specimens annealed 15 min. at 100° C. after rolling.

ect of copper on the creep-rate of lead would largely be due to the mechanical interference which the dispersed

5 Worner, H. W.—unpublished work, 1937.

particles of copper exert on the atomic movement. Above the creep-yield stress (defined in the previous article) this would be expected to lead to reduced creep-rate due to interference with movement within the crystal, the effect being greater the more finely dispersed the copper and the greater the copper content at least as far as the eutectic proportion of 0·06%. In general, these expectations are fulfilled.[3] It is of interest to note that the creep-yield stress (Fig. 2) appears to have been raised appreciably by the presence of finely-dispersed copper, but is unaffected by the more coarsely-dispersed copper.

Silver Lead Alloys

Tests at 20° C.—The alloys for these experiments contained 0·028, 0·049, and 0·099% silver, respectively. The production details of these alloys are similar to those for the copper-leads. The grain-size of the alloys was of the order of 0·1 mm. diameter. The creep properties of these under stresses of 500 and 350 lb./sq. in. were reported by Greenwood and Worner,[2] but at that time (1936) the tests at 350 lb./sq. in. had only proceeded for 100 days.

TABLE VII.—PERCENTAGE EXTENSION OF SILVER LEADS
(Stress, 500 lb./sq. in.   Temperature, 20° C.)

As rolled

Ag %	Duration (years)			Time to fracture and elongation		
	1	2	3			
0·0003 (U)	15·3	—	—	443 days	27%	—
0·028	5·4	11·3	—	1,065 ,,	31	I.C.*
0·049	4·0	9·6	21·5	1,245 ,,	50	I.C.
0·099	7·7	17·7	45·0	1,119 ,,	54	I.C.

Annealed 100° C. for 15 minutes

0·0003 (U)	—	—	—	280 days	24%	—
0·028	5·0	10·5	21	1,335 ,,	26	—
0·049	4·5	10·6	26	1,179 ,,	39·5	I.C.
0·099	7·7	16·8	44·5	1,112 ,,	50	I.C.

*Annealed 125° C. for 24 hours.   (Test started 3 weeks after quenching).***

0·0003 (U)	11·0	—	—	401 days	12%	—
0·028	5·5	10·5	26	1,085 ,,	26	I.C.
0·049	3·8	6·3	9·9	Unbroken 5 years	16·5	—
0·099	8·7	18·0	50	1,152 days	62	I.C.

* I.C. means that the test piece showed marked intercrystalline cracking.
** Another series of tests started within 2/3 hours of quenching gave a similar series of results.

TABLE VIII.—PERCENTAGE EXTENSION OF SILVER LEADS
(Stress, 350 lb./sq. in.   Temperature, 20° C.)

Annealed 100° C. for 15 minutes

Ag %	Duration (years)					Avg. over 5½ years
	1	2	3	4	5½	
0·0003 (U)	2·3	3·8	5·0	6·1	7·7	1·4%
0·028	1·0	1·9	2·7	3·6	4·7	0·85%
0·049	1·5	3·0	4·4	5·8	8·1	1·5%
0·099	1·8	3·9	5·7	7·7	10·4	1·9%

These results obtained with a stress of 350 lb./sq. in. have been plotted in Fig. 3. It will be noted that the relationship between extension and time is linear for the two higher silver alloys, whilst that for the 0·028% silver alloy shows a slight decrease in rate of stretch with time. For comparison, the curve UA for the basis lead shows a distinct and continuous decrease in the rate of creep with time.

However, in spite of the extreme precaution taken to reproduce conditions, entirely different results were obtained on an alloy containing 0·027% silver some two years later. The strain-time relationship for this is also shown in Fig. 5. It should have been a replica of the

one for 0·028% silver. Actually, the relationship was linear for one year and then showed a distinctly increasing rate of creep and after three years the test piece had stretched 16%.

A similar difficulty in reproduction of results even with the basis lead is illustrated by the curve UB. In this case the initial rate of creep was higher than with UA and the test-piece recrystallised after 4·8% extension after which the rate of creep steadily decreased. These are not isolated cases—each of these two types, UA and UB, has been duplicated at different times. This is evidence that the creep-rate is an extremely structure-sensitive property or else in experiments of this kind there is an, as yet, uncontrolled factor.

Tests at 50° C.—These tests were carried out simultaneously with those recorded in the last section and under identical conditions. The results are given in Table IX.

TABLE IX.—PERCENTAGE EXTENSION OF SILVER LEAD ALLOYS
(Stress, 350 lb./sq. in.   Temperature, 50° C.)

Annealed 100° C. for 15 minutes

Ag %	Extension in 300 days (%)		Ratio A/B
	50° C. (A)	20° C. (B)	
0·0003 (U)	6·2	2·0	3·1
0·028	3·7	0·8	4·6
0·049	7·2	1·2	6·0
0·099	15·3	1·5	10·2

After the 300 days under stress at 50° C. the specimens stood at ordinary temperature 14°/20° C. for eight and a half years. Table X gives the results of this further period.

TABLE X.—EXTENSION OF SILVER LEAD ALLOYS AT ORDINARY TEMPERATURE AFTER 300 DAYS AT 50° C.
(Stress, 350 lb./sq. in.   Duration, 8½ years.)

Ag %	Previous extension at 50° C.	New extension	Rate of extension at 14/20° C. % per year
0·0003 (U)	6·2	Broke 3½ years	—
0·028	3·7	7·8	0·9
0·049	7·2	18·0	2·1
0·099	15·3	>34	>4·0

Tests at 20° C. with superposed vibration.—These tests were carried out simultaneously with those on the copper leads, and after a similar series of treatments. In the case of the silver leads, the " billet anneal " carried out at 250° C. definitely reduced the proportion of silver rich phase, silver having a solubility of the order of 0·05% at this temperature.

The results for the two years with vibration and for the subsequent period of nine years without vibration are given in Table XI.

Summary of the Influence of Silver on the Creep-rate of Lead

These results should be read in conjunction with those reported in a previous paper[2] to which they are supplementary.

1. Tests at ordinary temperature (20° C.) under a stress of 350 lb./sq. in. show that 0·028% silver may reduce the creep rate of lead—on the other hand it may increase the rate (Fig. 5). Further additions up to 0·1% give rates of creep which in general are not greatly different from that of pure lead if the average rate is taken. The silver leads, however, tend to creep at a constant rate under a given load. In general, it would appear that silver is not a worth-while addition to lead

TABLE XI.—EXTENSION OF 0·028% SILVER LEAD ALLOYS

Treatment	Stress lb./sq. in.	With vibration		Without vibration	
		1 year	2 years	9 years	rate per year
Rolled direct	200	1·1	1·9	5·2	0·6
Annealed 100° C./15 min. ..	350	6·0	15[*]	Broke after 2½ years with further 60% extension	
" Billet anneal "	100	0·3	0·5	1·3	0·15
Annealed 100° C./15 min. ..	200	3·2	6·3	6·0	0·7
Rolled direct	200	1·2	2·4	8·2	0·9
Annealed 125° C./24 hrs. ..	350	8·0	21[*]	Broke after 1½ years with further 34% extension	

[*] Extrapolated from 600 days.

from the point of view of increasing the resistance to creep.

2. At 50° C. the same relationship holds in general, and as is the case with the copper alloys, ratio of creep rate at 50° C. to that of 20° C. increases with increasing silver content. The rate of extension at 20° C. appears to be rather greater after the extension at 50° C. than when the whole test was carried out at 20° C. (compare Tables VIII and X).

3. Under vibratory conditions even the 0·028% silver-lead alloy appears in general to be inferior to the basis lead, as the following comparison at the end of two years under vibratory conditions will show. The inferiority is more marked at the higher stress.

TABLE XII.—COMPARISON OF 0·028% SILVER LEAD WITH THE BASIS LEAD UNDER VIBRATION

Stress lb./sq. in.	Annealed 100° C./15 min.		Annealed 125° C./24 hrs.	
	U lead	0·028% Ag	U lead	0·028% Ag
200	2·8	1·9	0·95	2·4
350	9·2	15	4·0	21

4. Additions of silver appear to increase the extensibility under load. For example, under 350 lb./sq. in. stress the following values of extension to failure were obtained after two years under vibration and subsequent standing under load without vibration. All tests were simultaneous.

TABLE XIII.—EXTENSION TO FAILURE UNDER 350 LB./SQ. IN.

Description	Annealed 100° C./15 min.		Annealed 125° C./24 hrs.	
	Total time to fracture	% ext.	Total time to fracture	% ext.
U lead	8½ years	20	7 years	11
0·028% Ag	4½ "	75	3½ "	55

This effect of increasing the elongation at fracture has been found also in the case of tellurium and copper additions. It is characteristic of tensile creep (not necessarily with vibration) and may be associated with the finer-grain size of the alloys.

5. As silver is appreciably more soluble in lead than is copper, it would be expected that there would be greater internal resistance of the grain to deformation. If this is so, then the greater creep-rate of silver alloys must be attributed to movement at the crystal boundaries. It is strange, but true, that intercrystalline cracking in lead alloys is not incompatible with considerably increased elongations at fracture even though final fracture appears to be of a brittle nature. We have observed many such cases with different alloys. This observation does not apply to pure lead.

6. It has been noted that in certain cases silver can give rise to creep-rates which constantly increase with
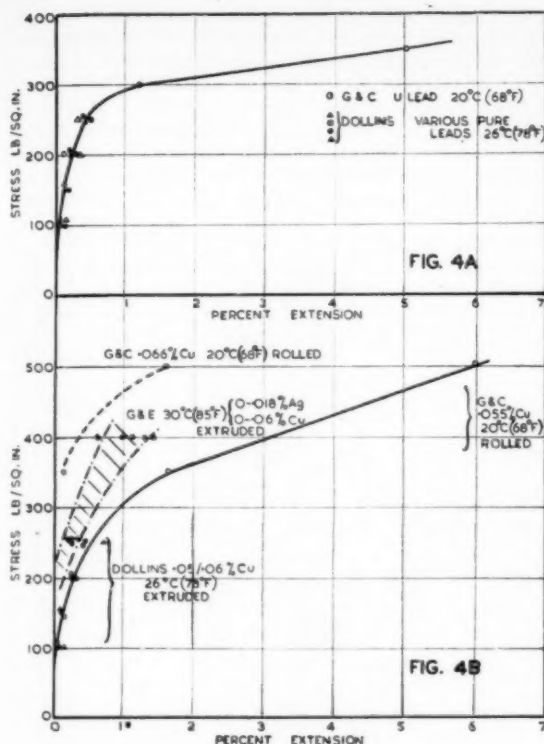
Fig. 4.—Creep-yield curve (total creep in one year) for various pure leads (4A) and copper leads (4B) at 20° C. (68° F.). Composite curves, including American results. (References 1, 7, and 8).

Fig. 5.—Creep-yield curves (total creep in one year) for various pure leads (5A) and copper leads (5B) at various temperatures. Composite curves, including American results. (References 1, 7, and 8).

time—type C curves[6]—similar to those which have been obtained with tellurium leads.

Dollins[7] in his summary (item 4) states : " This phenomenon (due to alloying) gives an intercrystalline type of failure common to most lead alloys subjected to a long-continued steady load. The ductility measured by the elongation after fracture is then lower than in the short test, where some of the failure resulted in slip within the grains." Our observations which are confined to rolled-lead strip lead us to the conclusion that whilst this applies to pure lead, it does not necessarily apply to alloys.

Practical Application of the Results

Two American papers have recently covered the industrial application of alloys of this type in connection with cable sheathing. One by Gohn and Ellis,[8] deals with the influence of small percentages of silver and copper on the creep characteristics of extruded lead. The other by Dollins [7] deals with the characteristics of various lead alloys, including some containing up to 0·07% copper. In assessing the value of results from the practical aspect it should be remembered that operating stresses must of necessity be of such a low order that changes of dimensions of more than 1% per year would not occur. This kind of order has been noted in lead chambers, but probably something appreciably less is all that could be tolerated in cable sheathing.

6 Greenwood, J. Neill, and Howard, K. Worner, *J. Inst. Met.*, 64 (1939).
7 Dollins, Curtis. W. Univ. Ill., Eng. Expt. Stn., Bul. No. 378, July, 1948.
8 Gohn, G. R., Ellis, W. C., *A.S.T.M.* Preprint, 1948.

Consequently, from the creep-yield curves for the basis lead previously given,[1] it is evident that at 20° C. (68° F.) a stress of 250 lb./sq. in. is the maximum permissible, and at 50° C. (120° F.) this is reduced to 150 lb./sq. in. From this aspect. the work of Dollins is very opportune, as all stresses applied were below the creep-yield stress. It is of interest, therefore, to compare his results with those of the present authors'. This has been done in Figs. 4 and 5.

In Fig. 4A a curve is given combining the results at ordinary temperatures for various pure leads, and it will be noted that results on several American leads conform very well with those obtained on lead from an Australian smelter. The experiments also indicate that similar results may be expected from lead whether rolled or extruded.

In Fig. 4B similar curves are given for a group of copper leads at ordinary temperatures. Again the results from the American leads are in conformity with the authors' results for an alloy of similar composition. On the same figure are plotted the authors' results for a slightly higher copper content (which has been found necessary to obtain the full benefits from copper additions). Also the results of Gohn and Ellis on a group of alloys ranging from pure lead to lead containing 0·018% silver and 0·06% copper are shown as falling between the two extremes. This appears to indicate that with copper leads the range of stress permissible for a creep-rate of 1% per year is associated with the structure and may vary between 300 and 450 lb./sq. in.

In Fig. 5A a comparison of creep-yield curves for pure leads at different temperatures is made from the combined results of Dollins and the authors. The results here are not so generally consistent — two distinct curves being obtained at 43° C. (110° F.) from two American leads. The Australian lead
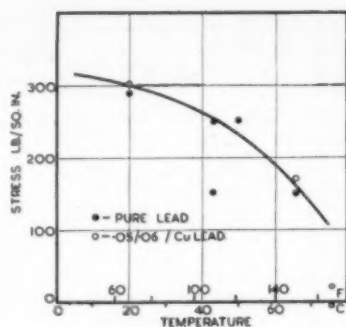
Fig. 6.—Stress to give 1% extension per year at different temperatures. Pure leads and copper leads—composite results.

at 50° C. (120° F.) gives a higher value than 1% per annum for the creep-rate at the creep-yield stress, but otherwise conforms to the general pattern.

In Fig. 5B similar results are plotted for copper leads at different temperatures from Dollin's work. At 66° C. (150° F.) there appears to be a considerable spread of results particularly for higher ranges of stress, which indicates another reason why design data should be obtained in the lower-stress range.

Finally, in Fig. 6 an estimate has been made of the stress which will give 1% strain per annum at different temperatures. This appears to be a useful design relationship for lead of composition falling within the classifications of desilverised, corroding and chemical leads. It is of interest to note from this curve that copper up to 0·06% makes no appreciable difference to the creep characteristics of lead, and that the process of manufacture also appears to be without appreciable effect.

A Vacuum Dilatometer for Routine Metallurgical Investigations

By T. Land, M.A., F.Inst.P., and B. Sugarman, A.R.C.S., M.Sc., A.Inst.P.

(The B.S.A. Group Research Centre, Sheffield)

The determination of the thermal-expansion coefficient of normal types of steel has been accomplished by the use of a vacuum dilatometer for routine work. This apparatus has been constructed as far as possible on geometrical-design principles, and is in continuous use in these laboratories. The instrument permits an overall accuracy in the thermal expansion coefficients of 1×10^{-7} per degree Centigrade, and utilises a specimen in rod form approximately 3 in. long. The expansion is transmitted to a dial gauge previously calibrated by means of a silica rod, the temperature being measured by a platinum 13% rhodium thermocouple placed in close contact with the centre of the specimen. Transformation temperatures are indicated to within about 2° C., and the apparatus is capable of operation up to 1,000° C.

THE changes in the physical properties of steels as they undergo transformations at high temperatures are of vital interest to the steelmaking industry. Several methods may be used to provide information on these changes, and this paper describes in detail a vacuum dilatometer designed and made in these laboratories, which for speed and simplicity of operation has proved most satisfactory in use almost continuously over the past four years.

Design Requirements

For routine investigations it is imperative that the sample be of such dimensions as to be easily produced, and the apparatus should be capable of yielding the thermal expansion coefficient up to approximately 1,000° C. to an accuracy rather greater than the fluctuations to be expected from different casts of the same nominal analysis. It was not envisaged that the apparatus should be used for steels having low coefficients of expansion such as " Invar," and thus an overall accuracy sufficient to enable the determination of thermal expansion coefficients to 1×10^{-7} per ° C. can be regarded as adequate for normal types of steel.

To prevent scaling of the sample at high temperatures the experiments should be carried out in a non-oxidising atmosphere, and for ease of experimentation it was decided to use a vacuum dilatometer. It was also a
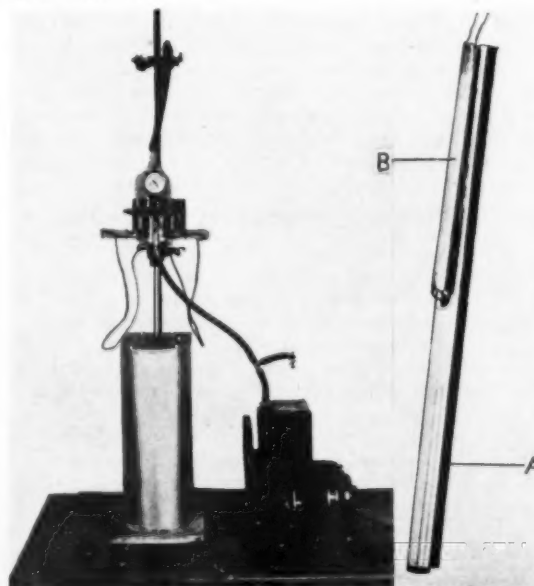
Fig. 1.
Fig. 2.
Fig. 1.—Complete apparatus. Fig. 2.—Arrangement of specimen with thermocouple.

requirement that the interchange of specimens should be possible with a minimum of adjustment and the maximum precision in positioning, and the instrument itself should be unaffected by vibrations and changes in ambient temperature, over long periods of time. Finally, it should be borne in mind that it was necessary for the transformation temperatures to be indicated to within approximately 2° C., in addition to yielding the coefficient to the above-stated accuracy.
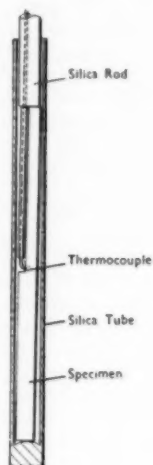
Fig. 3.
Arrangement
of specimen in
silica tube.
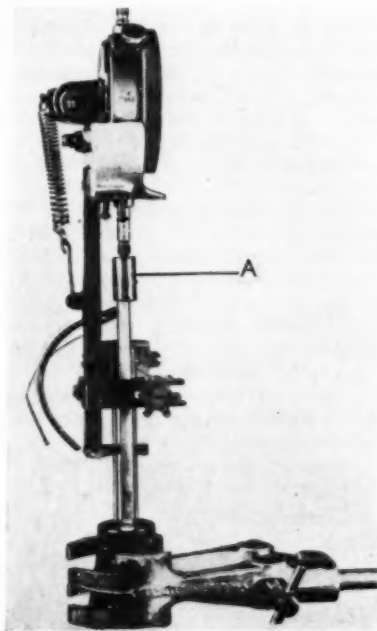
Fig. 4.—Assembled dial-gauge unit.

Operating Principles

A specimen, long enough to permit the determination of expansion coefficients to the accuracy desired, is heated in an electrical-resistance furnace, and the temperature raised at approximately 6° C. per minute. The specimen stands vertically in a closed-ended silica tube, and its expansion is transmitted to a dial gauge by means of a silica rod, which slides freely inside the tube. Readings of the gauge are noted at intervals of 5° C. or 10° C., and hence an expansion/temperature curve for the sample is obtained. The temperature of the sample is measured by a platinum/platinum - 13% rhodium thermocouple, the junction of which is in close contact with the centre of the specimen.

Design Details

The complete assembled apparatus is shown in Fig. 1. The specimen A (Fig. 2) is a rod 3 in. long, $\frac{3}{16}$ in. dia., and has a small hole $\frac{1}{16}$ in. dia., drilled diametrically at its centre, and a flat

ground by hand along half its length to accommodate the thermocouple sleeving B; the thermo-couple junction fits into the $\frac{1}{16}$ in. hole in order to ensure that good thermal contact is maintained between the couple and specimen. This (platinum-13% rhodium) couple (0·3 mm. dia. wire) passes freely down two holes within a silica rod. The specimen rests on the convex closed end of a vertical silica tube, 60 cm. long, 6 mm. bore (Fig. 3). The ends of the specimen are ground flat, and the silica push-rod is kept in contact with the upper end of the specimen by its own weight and the light pressure of the dial gauge return spring.
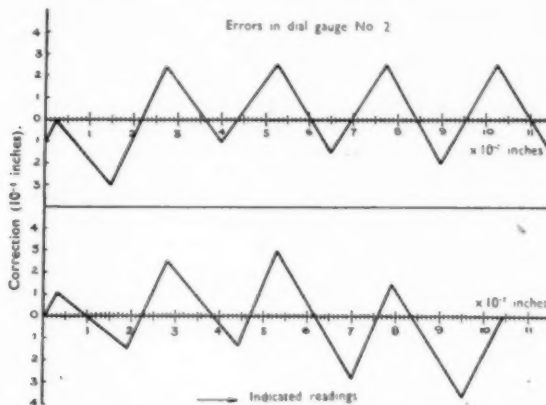
Fig. 5.—Errors in typical dial gauges.

In order to prevent slipping of the specimen within the tube while a test is in progress, it is adjusted into its position of lowest potential energy (see Fig. 3); this is achieved by tapping the silica tube until a minimum stable dial-gauge reading is obtained before commencing the test. Fig. 4 shows the assembled dial-gauge unit, the type of gauge used being calibrated in units of $\frac{1}{10000}$ of an inch. Such gauges have small systematic errors due to their mechanical construction, and must therefore be carefully calibrated by means of Johanssen
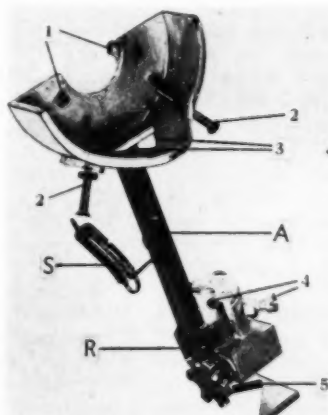
Fig. 6.—The clamping
arrangement.
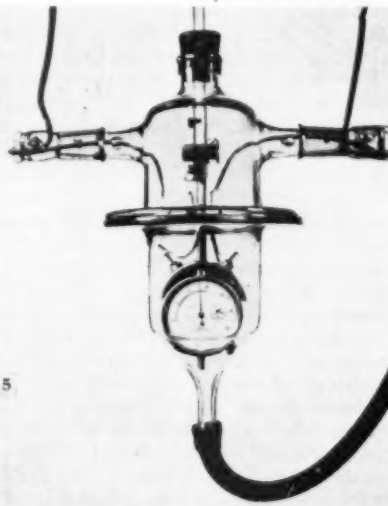
Fig. 7.—Showing the head and
dial gauge encased in glass.

slip gauges over the operating range. The errors of typical gauges are shown in Fig. 5.

In order to ensure complete reproducibility at each assembly of the apparatus, the clamp by which the gauge is attached to the silica tube is geometrically designed. The plunger of the dial gauge has a hemispherical end which fits into the conical hole in the brass cap A (Fig. 4) on top of the silica rod, and the points of contact between the gauge and clamp are arranged so that the silica rod can be centralised in the top of the silica tube, and the dial gauge aligned parallel to the silica rod, thus confining friction between the silica to a single point just above the specimen. If the silica is maintained above 1,000° C. for more than an hour or two, devitrification takes place and the friction is increased. When this occurs new silica tubes and rods are installed

The clamp is shown in Fig. 6, and will be seen to conform closely to the requirements of geometrical design, both in the clamping of the dial gauge and in the alignment of the silica rod. Consider first the dial gauge, in which complete rigidity is required—i.e., all six degrees of freedom are to be destroyed; this is achieved by two contacts (1, Fig. 6) on the back of the dial gauge, two (2) on the periphery, and a final two at the vee (3) which is brought into contact with the circular collar of the dial gauge. Restraining force is supplied by a single coil spring S, which, when attached (see Fig. 4), is
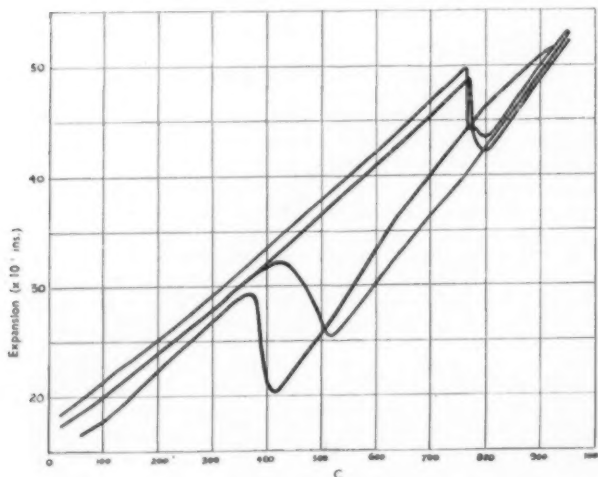
Fig. 8.—A typical curve obtained on a 1% chrome-molybdenum constructional steel.

so placed that it exerts a torque about contacts (2) as well as a direct force. The points of contact between the dial-gauge clamp and the silica tube consist of two screws (4), a vee (5), and a flat (R). The remaining degree of freedom (one of rotation between the axis and the tube) is destroyed by friction of the restraining spring R. This spring strip is situated considerably closer to the upper contact points than to the lower contacts at the vee, so that if the temperature of the clamp and tube change sufficiently to cause relative movement, all such movement will be at the vee and not at the upper contact points. Interchange of the specimens is accomplished by unhooking the spring, removing the dial gauge, and drawing out the silica rod to which

the thermocouple, which is inserted into the specimen, is attached.

The ambient temperature coefficient of the measuring head in dilatometers has been given careful attention in the present design. The bar A (Fig. 6) is made of special alloy steel having an expansion coefficient of approximately 8×10^{-6} per ° C., this steel being chosen so that when the temperature of the room changes the expansion of this bar exactly balances the sum of the expansion of the silica rod and the dial-gauge plunger.

The glass enclosure encasing the head and dial gauge (Fig. 7) is made in two halves, with a ground-glass seal and demountable thermocouple insertion plugs. It is not important to operate the apparatus at a high vacuum and, in point of fact, the narrow bore of the tube and specimen housing renders this practically impossible; it is only necessary to prevent major scaling, and it is not detrimental if the specimen after test shows slight temper colours.

The specimen is heated in a Nichrome-wound electric resistance furnace 17 in. long, and examination of the temperature distribution within the furnace showed variations of about $\pm 2°$ C. at 1,000° C. over the length of the specimen. The apparatus enables the change in length of the specimen to be measured to an accuracy of $\pm 10^{-4}$ in., if all precautions are taken and corrections are made for the dial-gauge errors. The dial gauge will be seen to be isolated from vibration, since it is supported by the rubber bung in the glass container, and no serious trouble from this source has been experienced. The vacuum is obtained by an Edwards' Hyvac pump.

Conclusions

The above-mentioned apparatus has been in satisfactory use in these laboratories over the past four years. and has given satisfactory service in routine determinations. A typical curve obtained on a 1% chrome-molybdenum constructional steel is reproduced as Fig. 8.

Renfrew Foundries.

RENFREW FOUNDRIES, LTD., Hillington, Glasgow announce that as from January 1st, 1949, fully-qualified sales engineers have been appointed to five areas, covering England, Scotland and Wales. They are as follows:—

Scotland: R. McGlashan, Renfrew Foundries, Ltd., Hillington, Glasgow. S.W.2. Tel.: Halfway 3391.

S. London and Southern England: J. S. Thompson, 53, Tudor Way, Hillingdon, Uxbridge, Middlesex. Tel.: Uxbridge 1633.

Midlands and Wales: J. A. K. Fergie, The Leys, Adderbury, Banbury, Oxfordshire. Tel.: Adderbury 224.

Northern England: A. J. Hebden, 41, Nab Wood Crescent, Shipley, Yorkshire. Tel.: Shipley 51929.

N. London and Eastern Counties: E. P. Mendoza, 16a, Green Court, Green Lane, Edgware. Middlesex. Tel.: Edgware 8954.

Renfrew Foundries have undertaken this reorganisation in order that their contact with industry, both in connection with sales and technical problems concerning aluminium-alloy castings, may be further improved.

Ironfounding and the Metallurgy of Cast Iron

By J. E. Hurst, D.Met., F.I.M.

Whatever aspect of the cast iron section of the metallurgical industry is chosen, production methods, plant and equipment, education and training, working conditions or the metallurgy itself, the detailed record of progress and development is one of outstanding achievement. In the present survey of progress in this field the author directs attention to cast-iron metallurgy, production methods, plant and equipment, and to foundry education and training, and research.

OVER the years that have elapsed since the beginning of the World War the whole of the metallurgical industry of this country can show a remarkable record of progress, and even the comparatively short period since the close of the war reveals no sign of interruption or cessation in this record. These remarks apply with just as much force to the section of these metallurgical industries devoted to cast iron and ironfounding as they do to the whole industry. Whatever aspect of the cast-iron section of the metallurgical industry is chosen, production methods, plant and equipment, education and training, working conditions or the metallurgy of cast iron itself, the detailed record of progress and development is one of outstanding achievement.

In any attempt at this time to review the importance of work in the field of ironfounding and cast-iron metallurgy, the metallurgical aspect can justifiably take first place. The discoveries made in the laboratories of The British Cast Iron Research Association, which have enabled cast iron to be produced with the whole of its graphite in a nodular form direct on solidification from the molten state, have solved for the first time a metallurgical problem in this field which has been sought after for many years by many people. In a series of papers in this country, America and elsewhere, Morrogh and his collaborators at The British Cast Iron Research Association have disclosed the details of their researches and the processes involved in the production of nodular cast iron, and these have been made the subject of various British, British Commonwealth and foreign patent applications.

Nodular Cast Irons

It is well known that ordinary grey cast iron contains graphite or free carbon distributed through the metal essentially in the form of flakes or lamellae. The relative brittleness and absence of ductility of ordinary cast iron is in a large measure due to the presence of this flake-like form and distribution of the graphite. In malleable cast iron, produced by the heat-treatment of white cast iron according to the conventional malleabilising process, the free carbon exists in the form of nodules These temper-carbon nodules as they are often referred to consist of spheroidal aggregates of graphite, and in this form do not exert such a deleterious influence on the mechanical properties as the flake-like form. These facts are well known, and it has always been obvious that if cast iron could ever be produced with the graphite in the nodular form an improvement in the mechanical properties would result. Hitherto the nodular form of graphite has been produced only in the malleable cast

irons by subjecting white irons to a subsequent heat-treatment process following upon solidification.

The method developed by the British Cast Iron Research Association enables nodular graphite structures to be produced in cast irons without the necessity for applying heat-treatment as in the malleable cast-iron process.

Stated in its simplest form, the process involves the solution of an appropriate amount of cerium in molten cast iron of appropriate composition shortly before casting. The principal composition requirements for the iron to be treated with cerium are :—

1. The iron must solidify grey even without the cerium addition.
2. The iron must be of hyper-eutectic carbon content, and the carbon content should exceed the value of 4·3 less one-third the sum of the silicon and phosphorus contents per cent. When the nickel content of an iron exceeds 10% ; it need not be hyper-eutectic according to this formula.
3. The silicon content can have any value, but is preferably within the range of 2·3–7·0%.
4. The sulphur content of the metal to be treated should be as low as possible, and after treatment it should not exceed 0·02%.
5. The phosphorus content must not exceed about 0·5%, and should be preferably below 0·1%.
6. Manganese, copper, nickel, chromium, and molybdenum may be present in any amounts, singly or in combination providing condition No. 1 is observed.

The most important of the above requirements are those covering the carbon and sulphur contents. After treatment with cerium the solidified castings must contain more than 0·02% of this element. The cerium is conveniently added as *Mischmetall* and functions first as a desulphuriser, and second as a carbide stabilizer. With cerium treatment alone only the hyper-eutectic graphite is nodular, and the remainder of the graphite is in a new pattern referred to as " quasi-flake graphite." The hyper-eutectic nodules are of the spherulitic variety. Nodular cast irons with all the graphite in the spherulitic form are obtained by treatment of the molten metal with cerium, followed by treatment with a graphitizing inoculant such as ferro-silicon or silicon-manganese-zirconium. The structural character of nodular cast iron prepared by treatment of a flake-graphite cast iron with cerium is admirably illustrated by a comparison of Figs. 1, 2, and 3. The composition and properties of these specimens are detailed in Table I.

The development of nodular cast irons is the outcome of many years of continuous research on the subject of graphite formation by the British Cast Iron Research
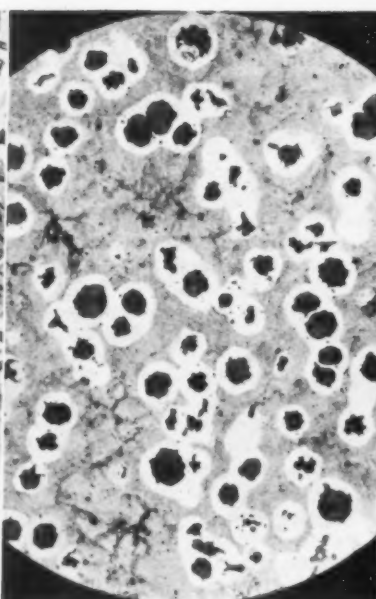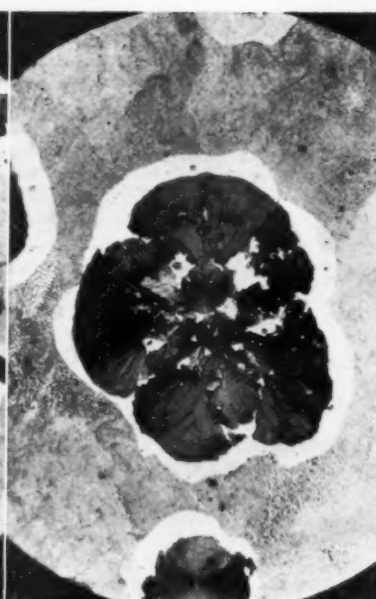
FIG. 1.   FIG. 2.   FIG. 3.

Fig. 1.—Flake-graphite iron, untreated. × 150.   Fig. 2.—Remelted Hematite, treated. × 100.
Fig. 3.—Illustration showing nucleation of hyper-eutectic spherulite. This shows a small spherulitic
hyper-eutectic nucleus surrounded by distorted spherulitic " eutectic " graphite. × 500

Association. It is a development which overshadows all others in this field of metallurgy, and this work associated particularly with the patient, arduous and elegant work of Morrogh and his collaborators must be acknowledged as classical both in its conception and execution.

Whilst the production of nodular structures provides an important field for theoretical speculation it is appropriate to consider the mechanical properties of the material with the new type of structure. Although the characteristics of nodular graphite resemble those of malleable cast iron, nodular cast irons are still relatively non-ductile and brittle. They do not exhibit a yield-point although their shock-resistance is very much superior to that of the best high-duty flake-graphite irons. Compared with flake-graphite irons, nodular cast irons can be produced having transverse-rupture stresses and tensile strengths as good as, and better than those of accepted high-duty cast irons. In addition, these high values may be obtained at a relatively low level of hardness and with shock-resistance figures as high as two to four times those of high-duty grey cast irons. It will be seen from these brief comments that these irons possess mechanical properties which might render the material particularly suitable in the field of engineering applications where high-strength and shock-resistance are required together with good machinability. By appropriate heat-treatment or by the use of special alloying elements the mechanical properties of nodular cast irons are raised to a very high level. A comprehensive survey of the comparative mechanical properties of

ordinary and nodular cast irons is to be found in the paper by Morrogh and Grant before the Institute of British Foundrymen in June, 1948.

Gaseous Annealing Processes for the Production of Malleable Cast Iron

The developments in the practical application of the gaseous process for the annealing of malleable cast iron fall naturally within a review of this kind. This process developed during the war years has now become a practical system for the annealing of whiteheart malleable castings. In this field the work of Robiette (Proc. I.B.F., 1944–45), and Jenkins and his collaborators (Proc. I.B.F., 1944–45–46) is specially noteworthy. The essential features of this process lie in the controlled decarburisation of the white-iron castings by annealing in a gaseous atmosphere of controlled composition. The most readily available sources of such gas mixtures are produced by the partial combustion of fuel gases such as Town's gas, producer gas or carburetted water gas. Under these conditions the packing of the castings in containers and with hematite ore can be dispensed with and with suitably designed furnace plant thorough malleabilisation is effected in relatively short cycles. Utilising electric furnaces and automatic-gas control, the whole process can be rendered fully automatic and indeed, if the type or production warrants it, and the cycle is a regular one, a programme controller can be installed. A predetermined heating, soaking and cooling

TABLE I.—ANALYSIS AND MECHANICAL PROPERTIES OF FLAKE-GRAPHITE AND NODULAR IRONS

Fig. No.	Description	T.C. %	Si %	Mn %	S %	P %	Ce %	Tensile strength tons/sq. in.	Transverse strength tons/sq. in.	Deflection	Brinell hardness No.
1	Flake Graphite	3·84	2·71	0·96	0·031	0·058	nil	7·74	—	—	103
2	Nodular	3·67	2·62	0·46	0·013	0·036	0·055	32·1	62·6	0·88	225

cycle is drawn as a curve, and the instrument will control the whole process to this actual cycle, thus bringing the white-heat malleable process truly into the category of precision operations.

General Metallurgical Progress

In the alloy cast-iron field progress continues in the accumulation of knowledge and experience of the properties and characteristics of the nickel-chromium and molybdenum alloys. The hard martensitic alloy irons of the nickel-chrome (Ni-hard) type, and the acicular irons containing molybdenum are the outstanding examples. It can be recorded also that the austenitic irons are suceptible to the British Cast Iron Research Association's nodular treatment with considerably improved results. Research work has made steady progress in the accumulation of knowledge of the gas contents of cast-iron alloys through the application of the vacuum-fusion and vacuum-heating techniques to this study. Progress in the development of spectrographic methods of analysis in addition to assisting in the routine analysis of cast iron has also enabled the study of the influence of residual or trace elements to be more readily pursued.

Production Methods, Plant and Equipment

In no other section of industry is there greater interest in the adoption and installation of mechanical aids of all kinds than the foundry industry. Apart from the large foundries with complete integrated production lines, many of the smaller foundries are finding the need for many items of mechanised equipment. Mechanical chargers for cupolas, moulding machines of various types, core-blowing equipment, Wheelabrator types of blast-cleaning equipment, centrifugal casting machines, sand-handling and preparation units, mechanical knock-outs and various types of conveyor systems for handling sand, boxes and molten metal, are typical examples of plant equipment engaging the attention of almost every foundry.

Considerable attention has been devoted to the subject of bonding materials for both moulding and core-making sand. The use of varieties of the plastic compounds available has been investigated in different directions. Improvements in results are claimed for such chemically-bonded sands, and there is no doubt that further progress will be made in this direction as the potentialities of these newer plasticisers are realised and become more widely known.

The successful development of permanent mould systems of iron-casting production has been described by Pollard and his associates under the title " Ferrous Die Castings." A full description of the details of the process and the wide range of castings produced from the Eaton-Erb machine is included in their paper before the Institute of British Foundrymen at their 1947 Conference.

Careful and active consideration is being devoted to the improvement in the general working conditions in foundries. The Report of the Joint Advisory Committee on Conditions in Ironfoundries issued by H.M. Stationery Office in 1947 presents an exhaustive study and recommendations on the part of the Garrett Committee of representatives of employers, trade unions and H.M. Inspector of Factories.

Foundry Education and Training, and Research

The ironfounding industry has now established its National Foundry College as one of a group of National Colleges established by the Minister of Education on the recommendation of the recent Departmental Committee on Higher Technological Education. In common with other national colleges it will be responsible for the highest education in the technology of the industry which it serves. It will undertake those activities in the field of foundry education which lie beyond the scope of colleges serving a single locality.

The National Foundry College is unique in that it is the successor to the British Foundry School, a truly national college, which was opened in the year 1935 as a result of the direct and public-spirited action of associations and firms within the foundry industry, led by the British Cast Iron Research Association. The school was assisted both by the then Board of Education, and the foundry industry. The industry continues to be well represented on the Board of Governors of the new National College through the whole of its technical institutions, research organisations and trade associations. Through those associations the industry is still giving generous financial and other support to the National Foundry College.

With the full concurrence of the industrial bodies supporting the college, the Ministry of Education has agreed with a Joint Education Committee of the Wolverhampton and Staffordshire Authorities, that the National Foundry College, while remaining a separate entity shall be conducted within the buildings of the Wolverhampton and Staffordshire Technical College and in close association with that college. The arrangements made ensure that students will have at their disposal not only the expert staff and the special technological equipment of the Foundry College itself, but all the resources of well-staffed and equipped departments dealing with the sciences and techniques ancillary to foundry work. There will also be available to them the library and the Institutional facilities of a large college ; and they will be able to associate with students following many different walks of life.

Under the aegis of the Council of Ironfoundry Associations the West Midland Foundry Advisory Committee have established the first Foundry Craftsmanship Training Centre in the country. On the recommendation of their Training Committee the C.F.A. decided to set up at least three Training Centres in different parts of the country. The West Midland Centre is located at the Works of Messrs. Rudge Littley, Ltd., West Bromwich, and is housed in a separate building alongside their foundry.

Modern plant and equipment is installed, most of which is on permanent loan through the generosity of the manufacturers.

Intensive training in craftsmanship will be provided for twelve to fourteen apprentices or trainees during a term of four weeks. These trainees will attend four terms at the Centre at intervals of nine months. Emphasis will be on practical training rather than lectures and educational studies.

The Centre will be under the control of a highly-skilled instructor working in collaboration with the Management Committee elected from the West Midland Foundry Advisory Committee. During their attendance at the Centre, trainees who have to be accommodated locally will be under the care and guidance of the instructor, not only in the evenings but also at the week-ends.

The twenty-seventh annual report of the British Cast Iron Research Association records the new membership basis which it describes as the most momentous change hitherto recorded in the history of the Association. Since its inception it has depended for its industrial support on voluntary membership by individual firms, who contributed in accordance with size, and although the actual subscription basis has been modified from time to time, its essentially voluntary character has not altered. The annual industrial income has been increased from £2,500 in 1921 to over £29,000 in 1947–48, and the number of member firms has increased from under 200 to 523. Nevertheless, for many years the Council have borne in mind the desirability of spreading the responsibility for subscriptions over the entire industry, which during the war comprised some 1,800 producing iron-foundries, and now comprises about 2,000. Since the whole industry benefits indirectly from the activities of the Association, it is equitable that all should contribute, and in no other way is it possible to contemplate the income of £100,000 per annum which, in the view of the Council is necessary to meet all the demands the industry is likely to make in future.

The Council, therefore, welcomed the proposals of the Joint Iron Council to broaden the basis of membership. During the war, the various trade association concerned with the manufacture of foundry pig iron, the ironfounding industry's primary raw material, joined together to form the Council of Iron Producers, while the various trade associations concerned with the ironfounding industry and working either on a specialised product basis or on a regional basis, came together to form the Council of Iron-Foundry Associations. These two bodies then constituted the Joint Iron Council.

As a result of an arrangement made by the Joint Iron Council, with the approval of the Iron and Steel Board, a substantial proportion of the Association's future income will come from a levy on foundry pig iron. For the year 1948–49 the total income from foundry pig iron sources will be £45,000.

In view of this change, which occurs at the close of the third year of a normal five-year grant period, the Council approached the Advisory Council to the Department of Scientific and Industrial Research for a revision of the grant terms. After consideration of the case put forward by the B.C.I.R.A. Council, the D.S.I.R. Advisory Council offered, and the Association accepted, a five-year grant arrangement, to date from July 1, 1948, based on a block grant of £20,000 for an industrial income of £45,000, together with a supplementary grant of £1 for £1 up to £20,000 for a further £20,000 of industrial income.

There will also be a very much closer degree of working between the Association and the Joint Iron Council on matters of general policy, as a consequence of the new financial arrangements, but the autonomy of the Association is in no way affected, and it remains under the government of the Council elected by members.

The changes referred to above have now been communicated to all grades of members of the Association, and, as far as has been possible from available records, to all producing ironfoundries in the United Kingdom.

International Nickel Directors Inspect Mines at Sudbury, Ontario, Canada

SIR WILLIAM T. GRIFFITHS, Chairman and Managing Director of The Mond Nickel Co., Ltd., is seen here with Mr. Robert C. Stanley, Chairman and President of The International Nickel Co. of Canada, Ltd., and other directors, who were present for the recent annual inspection of the Company's mines and plants in the Sudbury district of Ontario, Canada. The names of the Directors are given in the caption below.

(Reading left to right) :—James S. Duncan, R. Leslie Beattie, the Rt. Hon. Viscount Weir of Eastwood, Sir William T. Griffiths, H. C. F. Mockridge, Laurence S. Rockefeller, Dr. J. F. Thompson, Grant B. Shipley, Robert C. Stanley, H. R. MacMillan, John P. Bickell, William J. Hutchinson, the Rt. Hon. Viscount Margesson of Rugby, Dr. D. H. McLaughlin, Henry S. Wingate, Reg Halladay.

The Fracture of Metals

By C. F. Tipper, M.A., D.Sc.

Following the recent Annual General Meeting of the British Rheologists' Club, held at the Institute of Physics, a conference on The Fracture of Solids was organised by the Club under the Chairmanship of Professor N. F. Mott, F.R.S., the new President. Opening this conference Professor Mott pointed out that quite apart from its practical importance, fracture was the most interesting property of solids to the theoreticians because it is the least understood property, no progress having been made beyond the 1924 Griffith crack theory. It is not known how cracks exist nor what causes them. Experimental work has made clear what happens during fracture but not how it occurs. Four contributions to discussions on the subject were given ; Dr. C. F. Tipper described some experimental work on the fracture of mild steel ; Professor H. Moore discussed the fracture of glass ; Mr. H. Warburton Hall considered the fracture of plastics; and Dr. E. Orowan, F.R.S., spoke on the theory of fracture. The first contribution, that by Dr. Tipper under the above heading, is here presented and the remaining contributions will be published in succeeding issues. They are presented by courtesy of the Club and of the respective authors.

Dr. Tipper divides the fracture of mild steel into three types ; the first corresponds to a parting along a shear plane, the second along two intersecting planes, giving a wedge-shaped fracture, and the third along a plane quite different from the shear plane, often at right angles to the tensile stress. The main conclusion of her work on the subject is that fracture begins piecemeal at different places in the material, a fact confirmed by the work of Bridgeman in which a high hydrostatic pressure is found to increase ductility.

Introduction

THE most dangerous fractures in engineering service are those which occur unexpectedly in a material which is ductile by all ordinary standards of testing and might therefore be expected to deform plastically rather than break at points of high-stress concentration.

Fracture by fatigue is an example of such a failure. Another is the so-called brittle fracture of iron and mild steel, particularly at low temperatures, which has been known and has received spasmodic investigation on several occasions, without any rational explanation being found.

This type of brittleness has recently come to the fore once more as a result of the spectacular fracture of the plating in certain all-welded ships. During the course of an investigation into the causes of the initiation and method of propagation of a large number of fractures, some of which have occurred in service and others produced in the laboratory, it is possible to form a general picture of the process of fracture in alpha iron without, however, providing a complete explanation of all the observations.

Fracture of Metal Crystals

It is not possible to determine with certainty the crystal plane or planes upon which fracture takes place in a small-grained, poly-crystalline metal. On the other hand, the fracture plane of isolated metal crystals has been identified, and it would appear to be justifiable to assume that the same crystal planes take part in failure of the aggregate. Little is known about the stress conditions at fracture. There is good reason to think that fracture on a crystal plane will occur when a tensile stress normal to that plane reaches a critical value, but it is difficult to apply this criterion when fracture occurs upon planes which are also glide planes, and upon which shear may have already taken place.

There are three ways in which fracture is known to take place in metal crystals, and it is probable that alpha iron uses all three ways according to the conditions to which it is subjected.

1. The fracture plane may be crystallographically the same as the plane of shear. The angle which this plane makes with the direction of the principal tensile stress is generally between 40° and 50°, but depends upon the orientation of the crystal and the amount of deformation before fracture.

2. There is no well-defined plane, but a wedge is formed by two shear planes making equal angles with the direction of the principal tensile stress, or, if more planes participate, the crystal may draw down almost to a point.

3. The fracture plane may be crystallographically different from possible glide planes.

The chief difference between (1) and (3) is in the amount of distortion which takes place during the actual partition. Thus, the fracture plane may be roughened and have a matt surface or appear bright and polished. If the latter, as is generally the case in (3), the fracture is described as cleavage.

There are, however, considerable differences in both appearance and degree of distortion in crystals broken under different conditions.[1] For example, zinc crystals fracture at −180° C. on the basal plane of the hexagonal lattice, which is also the glide plane, after 200% extension and yet the surface is bright and polished. Other crystals which fracture on the glide plane e.g., aluminium-zinc[2] alloys, do so after only 10–15% extension, but the surface is matt and shows much distortion, Again, α iron crystals can be broken at low temperatures on planes parallel with the cube planes of the lattice Fig. 1, while β brass[3] having the same crystal lattice, cracks in a similar manner on the planes of shear (Fig. 3), of indices ¦110¦. In both instances, Figs. 2 and 4. the fracture planes are criss-crossed by the traces of intersecting planes and slip-bands. Although some of the examples quoted are alloys, there is no reason to think that this fact confuses the issue. *Solid solution* alloy crystals normally deform like crystals of the pure metal.

1 Boss, W., and Schmid, E., Kristall plastizität, Berlin, 1935, p. 178.
2 Elam, C. F., *Proc. Roy. Soc. A.*, 1927, **115**, p. 133.
3 Elam, C. F., *Proc. Roy. Soc. A.*, 1936, **153**, p. 273.
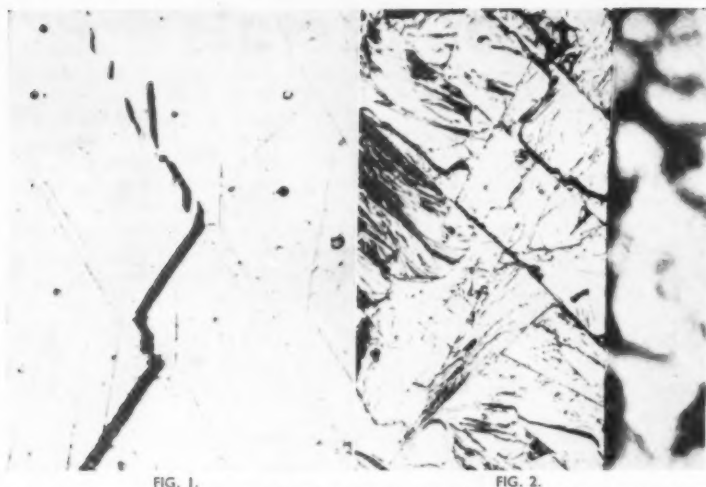
Fig. 1.—Cleavage cracks in a large iron crystal change direction in crossing Neumann bands. ×150   Fig. 2.—Surface of a cleavage plane and edge in iron.   ×150

The cleavage planes of certain minerals often show steps and striations which may be indicative of movement on intersecting planes. It is not difficult to imagine that with α iron very small amounts of shear on intersecting {110} planes could produce fracture on that {100} plane upon which the normal stress was highest, particularly in the presence of a crack of which the radius at the end was very small.

Cleavage fractures in an aggregate are always accompanied by some plastic deformation. In fact some deformation would appear a necessary accompaniment to make the cracks visible. The formation of Neumann bands on the cleavage planes of iron show that plastic deformation has also occurred before fracture and examples have been obtained of cracks breaking off and starting again when intersected by one of these bands. (Fig. 1).
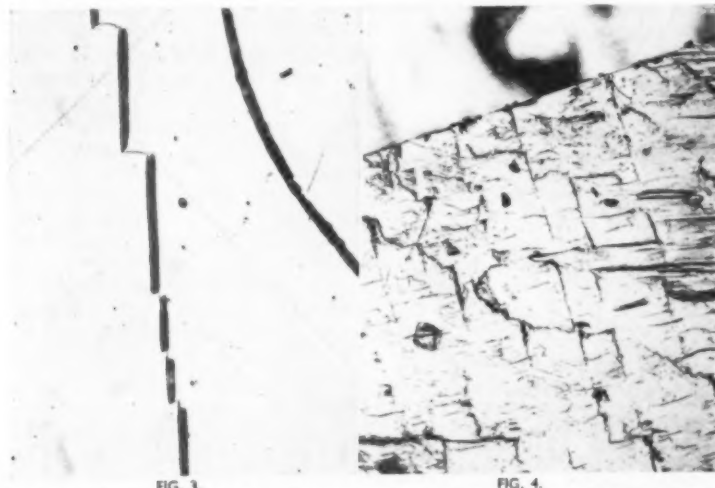
Fig. 3.—Cleavage cracks in a β brass crystal. The curved line is a crystal boundary.   ×150   Fig. 4.—Surface of a cleavage plane and edge in β brass.   ×150

Temperature and Fracture

It has been known for a long time that a tendency towards cleavage fracture in α iron increases as the temperature falls. The change in commercial steels may be gradual or sudden. Even if there is a range of 40° C., the change in mechanical properties as measured by rise in yield and ultimate stresses only amounts to a few per cent., and there is no measurable decrease in ductility. Hence, an increase in resistance to shear due to fall in temperature does not of itself appear sufficient to account for the change observed, and in fact, neighbouring crystals in the same section are observed to fracture or deform. In this connection it is interesting to recall the effect of orientation on the tendency to fracture. Experiments with bismuth[4] and tellurium[5] crystals have shown that below a certain temperature crystals of all orientations fracture in tension rather than deform plastically by glide or twin formation. Above this temperature only those crystals fracture in which the fracture plane makes an angle greater than a certain critical value, approximately 55° for bismuth.

Therefore, not only does the temperature decide whether a crystal shall deform by shear or fracture, but the orientation of the grains in a poly-crystalline aggregate relative to the tensile stress and to each other may also be a determining factor.

If such an effect could be shown to exist for α iron crystals, the change in fracture accompanying changes in temperature would be readily explained. Moreover, a tendency to a preferred orientation might explain the greater susceptibility of some steels to cleavage fracture. The existence of a preferred orientation has only been established in one plate so far. Further investigation would appear to be desirable.

The Fracture of Commercial Mild Steel

The appearance of the fracture of the poly-crystalline aggregate reflects the mode of fracture of the individual grains. The fracture may be wholly made up of types 1 and 2 above (Fig. 5), when the appearance is silky or fibrous, or a certain proportion of the grains may crack and break with little or no distortion (Fig. 6). Thus both forms of fracture occur in the same sample (Fig. 9). The proportion of each type in a fracture clearly determines the energy absorbed in its propagation as well as the velocity of propagation. The change in fracture does not always follow the energy absorbed in impact, as often a large proportion of the total recorded in such tests is absorbed before fracture begins. Where the

4 Georgieff, M., and Schmid, E., Z. Physik, 1926, 36, p. 759.
5 Schmid, E., and Wassermann, Z. Physik, 1927, 46, p. 683.

measurements of the energy to propagate a fracture have been made, there is a close relation to the type of fracture.

Although most of the cracks appear in the ferrite, numerous examples of their running through adjacent pearlite have been encountered (Figs. 8 and 9). Groups of ferrite grains frequently have very similar orientations. This is evident from the indistinctness of the intervening boundaries and fractures may be seen to run across such groups with little change of direction (Fig. 8). If such zones are favourably placed for the development of cleavage fractures they may contribute towards the easy initiation of such fractures and a heat-treatment which tends to produce groups of similarly orientated ferrite grains is clearly undesirable. A few isolated grains or groups of grains breaking in a brittle manner are often visible in an otherwise typically fibrous fracture.

Conditions Leading to the Initiation of Fracture

Most service fractures have been traced back to some sort of notch.[6] Fractures made in the laboratory have been started by the introduction of a notch perpendicular to the applied stress. The metal at the base of the notch yields at a mean stress, which agrees with that predicted from measurements of the stress concentration factor determined in an exactly similar test-piece of Columbia resin by photo-elastic means. Whatever the type of fracture there is always a plastic zone at the notch bottom, and in a normal fibrous fracture, it propagates at the mean breaking stress of the un-notched tensile test-piece.[6]

Thus, the metal at the base of the notch can be regarded as passing through all the stages that a test-piece of very short gauge length would pass through from yield to fracture. The machined notch ensures that the mean path of the natural crack is at 90° to the direction of loading. A notch at 45° does not lead to a brittle fracture under the same conditions of test.[6] As soon as the natural crack has formed, the shape of the original notch loses significance. A notch also ensures a relatively high rate of strain even under static loading, and this increases when the natural crack with its small radius at the end is formed. Although cleavage cracks form under static loads, they are more readily produced under impact.

The Shape of the Natural Fracture

Fracture is first visible in the centre of the notch bottom, often by the opening of a crack along a line of inclusions. The main fracture front is thus always ahead of fracture of the surfaces of a plate, to an extent which

6 Tipper, Elam, C. F., Admiralty Ship Welding Committee. Report No. R.3, H.M. Stationery Office, 1948.

Fig. 5.—Edge of a fibrous fracture in mild steel.   × 100   Fig. 6.—Cracks in a mild-steel plate separated by unbroken metal.   × 150

FIG. 5.   FIG. 6.
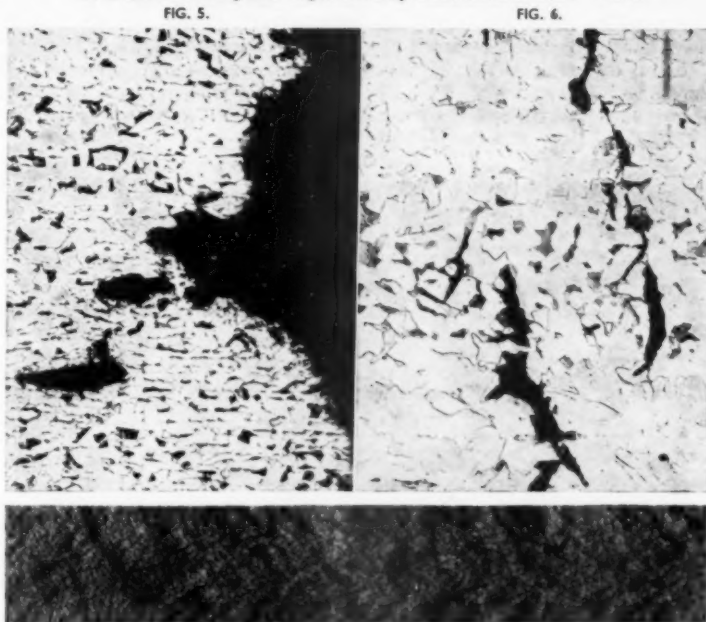
FIG. 7.

Fig. 7.—Surface of a fracture showing chevron markings produced by alternate zones of cleavage and fibrous fracture. Slightly enlarged.

varies with the material, the thickness of the plate and temperature of test. This shape persists at distances far removed from the original notch. There is nothing essentially different from the sequence of fracture in a round bar in tension shown by Ludwik to start in the centre. Whereas, in the round bar it is very difficult to arrest the fracture at different stages, these stages can be studied in reverse order in the same specimen by cutting sections through an arrested fracture in a plate.

FIG. 8.   FIG. 9.
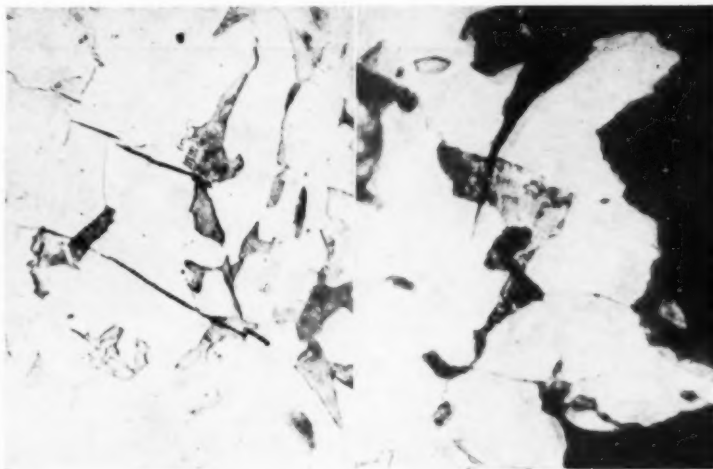
Fig. 8.—Same as Fig. 6, showing fine cracks in certain crystals.   × 500
Fig. 9.—Edge of fracture.   Cleavage crack running in from the surface, crossing pearlite, adjacent crystals distorted.   × 500

It has not been possible to stop and examine the ends of any of the most brittle fractures without some uncertainty arising as to the conditions being exactly those which exist while the fracture is progressing. The study of the ends of less brittle and fibrous fractures and sections through numerous brittle fractures have enabled us to investigate their structure and thus to hazard an explanation of their method of propagation.

of inclusions can also divide the section into groups of crystals, each one of which may be regarded as a separate tensile test-piece which can deform by shear far easier when freed from transverse restraint.

In both instances, the holes are finally joined by fine cracks and the fracture is complete. The two types are illustrated diagrammatically in Figs. 11 and 12.

Diagrammatic drawings representing sections through
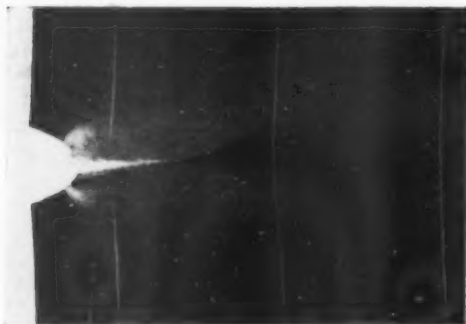
Fig. 10.—Fracture starting from a notch. Note shape of the plastic zone. Sections through this are shown diagrammatically in Fig. 11. Full size.
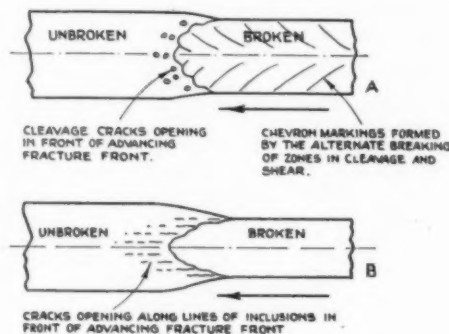
Fig. 11.   Fig. 12.—(a) Brittle-type fracture ; (b) fibrous-type fracture.

In front of the advancing crack on the surface is a zone plastically deformed (Fig. 10), which is very small in brittle fractures, but may be spread over the whole plate in the most ductile. Sections through this zone enable the depth to which the centre has broken to be determined. The outline of the separated parts is irregular and finally consists of holes separated by unbroken metal. Some of the holes are formed by the cracking of a crystal or a group of crystals and their separation by subsequent deformation of the unbroken metal. An example of such a fracture is shown in Figs. 6 and 8. Thus, on the fractured surface, troughs alternate with ridges, giving rise to the chevron pattern so characteristic of many of these fractures (Fig. 7).

While the fracture of ductile material cannot be explained in quite the same way, separation along lines

the fracture are given in Fig. 11. No. (1) shows the two parts fully separated ; (2) represents a section before the point of visible cracking on the surface ; and (3) near the end of the fracture where the metal is divided into separate sections. The mean fracture path is still perpendicular to the direction of loading. In No. (4) the mean fracture path is at 45° to the direction of pulling, a change which takes place in very ductile steels and results in the typical appearance of most fractures in mild-steel plate.

Fig. 12 is a diagrammatic drawing of the advancing fracture seen in plan. A represents a fracture in which a number of the crystals break by cleavage, while B is representative of a wholly fibrous fracture. Separation along lines of inclusions also takes place in A, but the

FIG. 13.   FIG. 14.   FIG. 15.

Fig. 13.—Hole forming round inclusion.   × 800   Fig. 14.—Holes formed round inclusions tend to lie on 45° lines to direction of loading.   × 80   Fig. 15.—Opening of large flaw crossing fracture. Note the plastic deformation on either side.   × 80

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fissures caused by this process have been ommitted from the diagram to avoid confusion.

In ductile steels the holes almost certainly originate by the drawing away of the metal from non-metallic inclusions. This process may begin at an early stage, probably at the yield point. Fig. 13 shows such a hole forming round an inclusion. Separation has hardly begun in the upper inclusion. Near the main fracture, the holes become so large (Fig. 5) that the inclusions generally drop out during the preparation of the section (Fig. 14).

The influence of structure on mechanical properties, apart from composition is well known. It is only necessary to mention the lower values for elongation and more especially reduction in area in a tensile test and the energy absorbed in impact tests when the test-pieces are cut across the direction of rolling. Since inclusions are elongated by the working they are more dangerous when they are placed with their long axes perpendicular to the principal tensile stress. In this position also, there are more " ways through " for the advancing fracture of whatever type. Cracks meeting an inclusion or hole may be diverted or stopped if the discontinuity affords relief of stress, so that inclusions may act in two capacities (Fig. 15).

At what stage do cracks and fissures form ? It has been suggested above that separation between metal and non-metallics may begin at the yield-point. Separation would be expected to increase rapidly at the point when a neck forms in a tensile test-piece or near a notch. Hence, Bridgman's observations on the increase in ductility caused by testing under high hydrostatic pressure, and the large extensions obtainable in wire-drawing and rolling may be regarded merely as the results of closing the flaws.

These observations refer chiefly to the fracture of mild steel, but they can be applied to explain the fracture of all poly-crystalline aggregates, since internal flaws are necessarily present, although differing in both sizes and form.

Conclusions

The observations which have been made on the fracture of iron and mild steel lead to the following conclusions.

Two types of fracture are met with ; one in which the crystals crack after little deformation, and the plane of fracture shows only slight distortion ; the other, in which the crystals are drawn out into fibres. Evidence of cracking in advance of the main fracture front has been obtained. Separation of the metal around inclusions has been shown to occur at some distance from the advancing crack. The holes produced by either method are linked by the elongation and fracture of the metal between them.

An increase in the number of crystals breaking in cleavage as the temperature falls may be due to an increase in resistance to shear and to the influence of orientation of the grains on the incidence of cleavage.

The work on the fracture of mild steel was carried out in the Engineering Department, Cambridge University, under the direction of Professor J. F. Baker, O.B.E., Sc.D., on behalf of the Admiralty Ship Welding Sub-Committee.

Metro-Cutanit, Ltd.

THE Warrington works of the Metropolitan-Vickers Electrical Co., Ltd., have been engaged in the manufacture of sintered carbides under an agreement by which the whole of the output was sold to Cutanit, Ltd. A new Company has now been registered under the name of Metro-Cutanit, Ltd., to take over and combine the production of the Warrington works with the technical and commercial activities at present carried out by Cutanit, Ltd., and by Compound Electro-Metals, Ltd. The Registered Office of the Metro-Cutanit, Ltd., will be at 42, Pall Mall, London, S.W.1, and the Warrington works will be owned and operated by Metro-Cutanit, Ltd., as from January 1st, 1949.

Metropolitan-Vickers has a substantial interest in Metro-Cutanit, Ltd., and the Board of the new Company consists of an equal number of directors, appointed by Metropolitan-Vickers and Cutanit, Ltd., respectively, Mr. I. R. Cox, D.S.O., Managing Director of Metropolitan-Vickers being Chairman of Metro-Cutanit, Ltd.

The new Company will commence operations with a large and active interest in the production and sale, under the registered trade mark " Cutanit " of metallic carbides of all kinds for use in cutting tools, drawing dies, wear-resisting parts, etc. Another branch of the business will be the production and sale, under the trade mark " Elmet " of compound metals for use in switchgear, resistance-welding equipments, bearings, etc.

The Warrington factory has excellent up-to-date equipment and its manufacture is backed by the great technical resources of the Metropolitan-Vickers Research Department whose contribution in the development of carbides is well known. With these advantages and its own highly skilled and experienced staff, Metro-Cutanit, Ltd., will be able to offer not only high-grade manufacture but also valuable advisory service.

The main distributors for the carbide products of the new Company are Messrs. Wm. Jessop & Sons, Ltd., the well-known steel manufacturers of Sheffield.

German Gas-Turbine Developments during 1939-1945

B.I.O.S. Overall Report No. 12, is devoted to an analysis of the many different German ideas which went into their gas turbine research and manufacture. The report deals with the design of the various components, such as compressors, turbines and blade cooling, combustion, fuel systems and heat exchangers ; another section is concerned with a review of the various applications of gas turbines, including the interesting Lurgi gas turbine, a 12,000 k.w. power-generation project which was intended to utilise gas from high-pressure gasification of brown coal. A high capital cost could be offset against an efficient power source from low-grade fuel. Owing to their lack of high-grade alloys, the Germans were forced to evolve various designs of hollow blades with internal cooling, partly by air and partly by water at its critical temperature. On rotary heat-exchangers for gas turbines, German developments were ahead of similar work in this country, and much of interest can be learned from them. Another interesting piece of research was the use of mixed sintered iron and alumina to produce a material for blades at high temperatures.

The report contains 46 pp. and several diagrams as well as 46 references to other published information on German research and a subject index. Price 1s. (post free, 1s. 1d.).

Staff Changes and Appointments

MESSRS. BROWN BAYLEY'S STEEL WORKS, LTD. announce the following changes, dating from January 1st, 1949 :—*London Office*—Mr. H. E. CLARK succeeds Capt. M. K. F. Saunders as Office Manager. *Birmingham Office*—Mr. E. W. FIDDIAN succeeds Mr. R. U. Bailey as Office Manager, and Mr. A. HEWER has been appointed to the Area. *Sheffield*—Mr. P. KEMP succeeds Mr. H. E. Scott as the Sheffield representative.

Dr. HAROLD HARTLEY, Deputy Chairman, has been appointed to succeed Mr. J. F. Davies as Chairman of Radiation, Ltd. Mr. DAVIES retired from the board on December 31st, 1948.

Mr. JOHN RAE, Jr., A.I.M., formerly works director of the Birmingham works of McKechnie Bros., Ltd. has sailed for South Africa, to take up the position of Joint Managing Director of McKechnie Brothers, South Africa (Pty.), Ltd., Germiston. Correspondence may be addressed to him at P.O. Box 382, Germiston, Transvaal.

Mr. G. H. JARRAMS has been appointed Joint Chairman and Managing Director of Thomas Andrew & Co., Ltd., of Sheffield.

Mr. A. F. BEECH has been appointed a Director of the Halesowen Steel Co., Ltd., in succession to the late Mr. W. H. Spendlove.

Dr. C. SYKES, F.R.S., and Mr. D. A. OLIVER have been appointed to the National Committee for Crystallography under the Chairmanship of Sir Lawrence Bragg.

Mr. H. H. ASCOUGH, Assistant Works Manager at the Port Talbot and Margam Steelworks, has been appointed Mills Superintendent at the new Abbey Works at Port Talbot. The Steel Company of Wales have appointed Mr. J. LYSAGHT to be Manager of the Sheet Mill Department at the new works.

Mr. G. ARCHER and Mr. L. K. BRINDLEY have been appointed Directors of the Mond Nickel Co., Ltd.

Smith and McLean, Ltd. have appointed to the board Mr. J. BRYDEN, former Works Manager of the Gartcosh Works, Mr. J. W. STEWART, the present Works Manager, and Mr. R. STEWART, Works Manager of the Mavisbank Works.

Mr. F. BROWN, Secretary, and Mr. T. M. ELLIOT, Chief Metallurgist, have been appointed Special Directors of Messrs. Arthur Lee & Sons, Ltd.

Mr. G. MURFITT is relinquishing his appointment as Chief Chemist to the B.S.A. Group Research Centre and William Jessop & Sons, Ltd., to take up a senior appointment with Metals and Methods, Ltd.

Mr. A. W. BURTON has been appointed Managing Director of the District Iron and Steel Co., Ltd., Smethwick. Mr. J. R. BROCKHOUSE and MAJOR C. R. DIBBEN have also joined the board.

Mr. GLANVILLE JONES has left the United Steel Companies, Ltd., to become Chief Metallurgist at the Panteg Works of Messrs. Richard Thomas and Baldwins, Ltd.

Mr. G. R. WALSHAW has retired from the Appleby-Frodingham Steel Company.

Mr. L. J. A. HAYWOOD, Chief Chemist, Catton & Co., Ltd. has now been appointed Chief Chemist and Metallurgist, in charge of steel manufacture, treatment and analysis.

Dr. D. S. LAIDLER has left Wild-Barfield Electric Furnaces, Ltd., to take up an appointment as Assistant Research Manager of Goodlass Wall and Lead Industries, Ltd., at Greenford, Middlesex.

Mr. F. S. BEALE, Secretary of the English Steel Corporation, has been appointed a Special Director.

Mr. R. W. PAYNE has succeeded the late Mr. A. C. Bernard as Manager of the Carron Company.

Dr. F. ADCOCK is to take charge of research for the Broken Hill Proprietary Co., Ltd.

Mr. N. S. ANGUS has been appointed Metallurgist to the Production Engineering Research Association.

THE EARL OF DENBIGH has been appointed Chairman of John Bedford & Sons, Ltd., of Sheffield. Mr. JOHN BEDFORD becomes Vice-Chairman.

Mr. H. A. CHAMBERS has been appointed General Manager of the Rockwell Machine Tool Co., Ltd.

ROBERT BARAR, M.C., B.Sc., M.B., B.S., M.A., of the Department of Human Anatomy, University of Oxford, has been appointed Alan Johnson, Lawrence and Moseley Research Fellow of the Royal Society. He will continue his work at Oxford on the biological and medical applications of new methods of microscopy.

DR. F. A. FOX has relinquished his appointment as Deputy Director of the British Welding Research Association and is joining Messrs. H. J. Enthoven & Sons, Ltd., as Deputy Technical Manager. His new address will be 15, Lime Street, London, E.C.3.

SIR JOHN S. BUCHANAN, C.B.E., F.R.Ae.S. has joined the board of Dualloys, Ltd., of Boden Works, Chard, Somerset, the well-known manufacturers of bearings and non-ferrous metals.

Sir John, a Whitworth Scholar, acquired his early engineering training with G. & J. Weir, Ltd. His wide experience of the engineering industry has been gained in such appointments as H.M. Inspector of Factories (1908), Deputy Director of Research and Development of Aircraft, Director-General of Aircraft Production (1941), Assistant Chief Executive of the Ministry of Aircraft Production (1943–45). In 1945 he was appointed Technical Director of Short Bros., Ltd., the aircraft manufacturers.

Gold Buttons for 25 years Work

EACH member of the staff of Mond Nickel who has served the Company for twenty-five years, is being presented with a gold button by Sir William T. Griffiths, Chairman and Managing Director. There are 526, including a sprinkling of women employees (who receive a gold pin instead of a button) eligible for this recognition. They all belong to the Company's Quarter-century Club.

Board Meets Workers

A MEETING of the workers, attended by over 500 representatives of the 30,000 employees of Tube Investments, Ltd., was held at the Broadwell Works, Oldbury, Birmingham, recently.

The meeting was addressed by Mr. I. A. R. Stedeford, the Chairman, and other members of the Board, who described the present position of the 37 subsidiary companies in the Group, discussed their economic and industrial operations and problems, and dealt with future prospects.

After questions, the representatives inspected an exhibition at the works, showing the Group's main products and their industrial applications.

The meeting was arranged as a further development in TI's policy to ensure that those employed by the company should have full and first-hand information about its activities and future policy.

THE ELECTRON MICROSCOPE

By A. D. Merriman, G.C., O.B.E., D.Sc., M.A.

Although the first commercial electron microscope was made several years ago, the numbers in use in any particular branch of science are still quite small. In this article, the author compares the optical and electron microscopes with regard to construction and performance, and discusses the means whereby the instrument may be used to examine metallurgical specimens.

ANY optical system—simple or complex—which can be used to magnify small objects may be called a microscope. Ordinary "magnifying glasses" consisting of convex lenses, have been known —at least as curiosities—from remote times, but the compound microscope dates from some time between 1590 and 1610 A.D. The actual date is rather uncertain, but Galileo, the astronomer, is one to whom is ascribed the honour of inventing the first telescope and then the microscope. During the 17th and 18th centuries important discoveries in biology were made, directly due to the use of the microscope. Such names as Leeuwenhoek—the father of modern microscopy and, Malpighi—the Italian, who verified the circulation of the blood, readily come to mind, but, perhaps, the most important name associated with the perfection of the microscope as a scientific instrument is that of Ernst Abbé. It is to the researches and discoveries of Abbé more than to any other single person, that the high state of perfection of the modern microscope is due. But since the appearance of the achromatic objective about 70 years ago, there has been a pause in further developments. Even Abbé was aware that there were theoretical limits to the resolving power of any optical system—a fact that is said to have greatly depressed him.

Wavelength and Resolution

It is, of course, possible to enlarge an image almost without limit, but is obvious that when further enlargement fails to reveal additional detail, the limit of useful enlargement has been reached. The normal eye can *just* distinguish as separate entities two small spots which are not closer together than 200 microns, a micron being 1/25,000 of an inch. The object of using a microscope is thus to resolve two points which are closer together than 200 microns and cause them to appear as two separate entities.

Acceptance of the wave theory of light leads to the conclusion that two objects which are closer together than about one-half of the wave-length of the light used cannot be resolved. When blue light is used—such light having the shortest wave-length of the visible spectrum —it will be clear that the useful magnification can only be about 1,000 diameters. For the wave-length of such light is of the order of 0·4 microns and when 200 microns is divided by half this wave-length the resulting magnification is 1,000. Hence it appeared that progress in microscopy would be dependent upon the discovery and utilisation of much shorter wave-lengths. The discovery, during the early years of the present century, of X-rays raised some hope that a very powerful microscope was within sight since the wave-length was only about one-ten thousandth part of the wave-length of light. But that hope disappeared when the properties
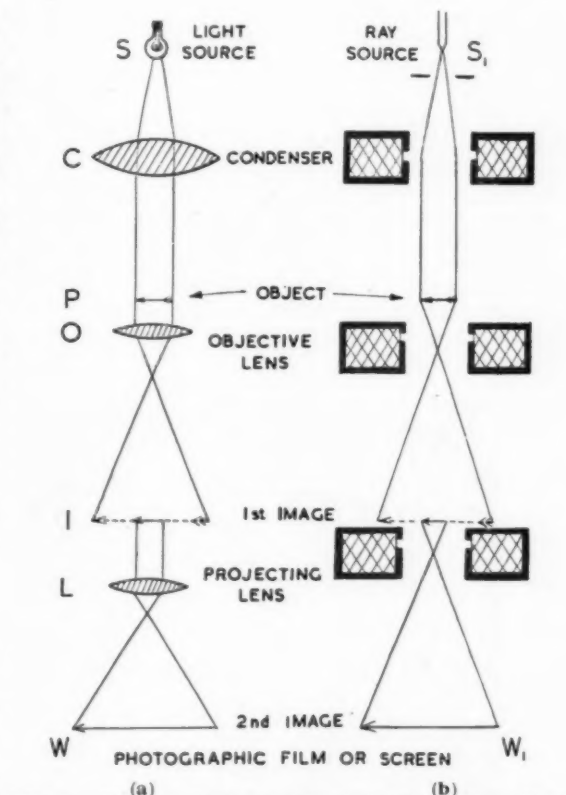
Fig. 1.—Diagrammatic arrangement of (a) the optical microscope and (b) the electron microscope.

of X-rays were investigated, for optical lenses were obviously unsuitable for use with X-rays and no method could be found to focus them.

Not much more than 25 years ago, as the result of the vast amount of work done on the subject of cathode rays and their properties, it came to be realised that the stream of electrons issuing from the cathode of a "discharge tube" could be regarded as functioning with a wave-length of the same order as that of X-rays. But there was the added importance in this case, that the electron beam could be focused by the application of suitable magnetic or electric fields. Theoretically, magnification in the electron microscope could reach a value of 100 times that of the best optical microscope. In practice, it has been found convenient to accept magnifications of about 50,000 diameters as a good performance.

Development of the Electron Microscope

The evolution of the electron microscope has proceeded mainly by reproducing the main parts of the optical projection microscope, modifying each part so as to be capable of dealing with cathode rays rather than light rays. In Fig. 1 (*a*) is shown in diagrammatic fashion the arrangement of an optical microscope. The light source is at *S* below which is the condenser lens *C*, the function of which is to collect a wide beam of the light radiation and concentrate it upon the object *P*. Rays from the illuminated object then pass through the object lens *O* and there results a real and enlarged image of *P* at *I*. This latter is then further magnified by the projection lens *L* and the final image is produced on the screen at *W*.

The arrangement in the electron microscope is shown in Fig 1 (*b*), when the similarity to Fig. 1(*a*) will easily be recognised. Here *S*, is not a light source but a heated cathode in a vacuum tube and the screen *W*, is not a white surface, but a specially prepared fluorescent screen. The special type of lens too, merits a short description. It consists of a large number of turns of wire forming a coil which is housed in a steel casing and provided with pole pieces as illustrated in Fig. 2. The pole pieces are movable so that the same construction can be used for the condenser lens – where the pole-pieces are at the centre of the coil, and for the object lens and the projection lens – where the pole-pieces are at the top of the coil. Actual focusing is not affected by moving the lenses as in the case of the optical system but by varying the current through the coils.
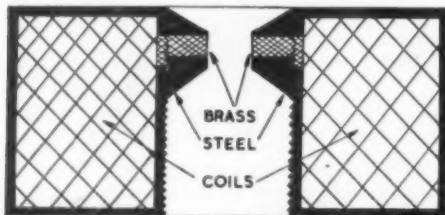
Fig. 2.—Electron microscope " lens."

Aberration

Any optical system may suffer from two defects — one due to the curvature of the lens and the other due to the composite nature of ordinary white light. When these defects are reduced or eliminated the lens system is said to be " corrected ". The correction of an optical system is made possible by using lens combinations in which the components have equal and opposite dispersions but different deviations and by using small apertures.

But a " corrected " electron lens has not so far been produced, and there appears to be little prospect that this can be achieved. What corresponds to chromatic aberration in an optical lens does occur in an electron lens and is due to the electrons not all travelling at the same velocity. The obvious cure is, of course, to maintain the anode voltage constant within very narrow limits and to ensure that the space between the electrodes is as free as possible from gas molecules. which by collision with the electrons would reduce the velocity of the latter. " Spherical " aberration has its counterpart, too, and the method of reducing the effect is to employ very small apertures. The small apertures required would
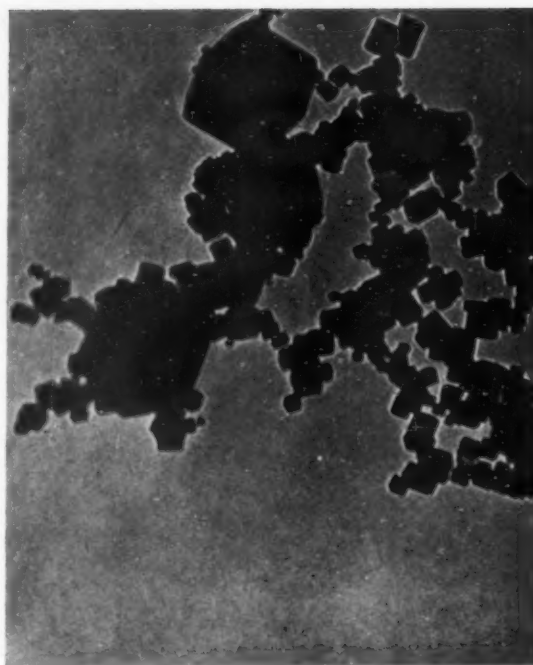
Fig. 3.—Electron micrograph of magnesium oxide smoke.
× 55,000.

be quite impracticable with an optical system but work well enough in an electron microscope because of the very high intensities which can be obtained in the electron beam.

To give some idea of what this means it may be mentioned that the greatest light intensity obtainable in optical work is that due to the sun but with a barium coated cathode and an accelerating (anode) voltage of 60kV, the energy obtainable is of the order of more than a million times that obtainable from solar radiation on a similar area placed outside the terrestrial atmosphere : this explains why apertures of one hundredth or even one thousandth of those used in ordinary microscopy are effective.

It is well-known that in the ordinary optical microscope the different absorption of light in different parts of the specimen being viewed is the origin of the contrast of the image. It is not surprising therefore to recall that the early experimenters considered that the main condition of success in obtaining a satisfactory electron image was to employ substances showing considerable differences in electron absorption. This was the reason for impregnating the specimens before observation with salts of heavy metals. More recent investigators have shown, that when very small apertures—of the order of about one thousandth of an inch—are used, impregnation is unnecessary, The fast moving electrons, by collision with the atoms of the substance under consideration, lose some of their energy and hence these electrons will be missing from the beam which would otherwise have produced a uniform effect upon the photographic plate. Now it has been pointed out that differences in electron velocity is analogous to chromatic aberration in ordinary optical systems, and thus it may be concluded that " chromatic " aberration in an electron lens is beneficial
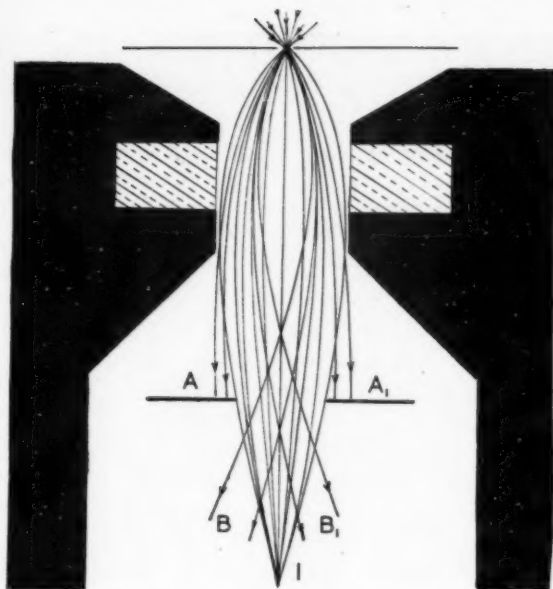
Fig. 4.—Effect of aperture, placed below pole-pieces of electron " lens," in cutting out some of the slower moving electrons.

History

The appearance of electron microscopes for commercial and research use dates back only about 16 years. The first electrostatic instrument was that built and described by Knoll and Ruska in Berlin in 1932. It is shown diagrammatically in Fig 5. Among other early types was one produced in 1934 by Marton in Belgium. His microscope was elaborated to include an air-lock for changing specimens without losing the vacuum in the main volume of the microscope. He was the first observer to investigate biological specimens with an electron microscope. This was followed in 1936 by the MV model produced by the Metropolitan-Vickers Electrical Company. This latter used a " cold " cathode and the general contour followed that of the earlier metallic cathode ray tubes. Two years later appeared a somewhat simplified design using a " hot " cathode. Since 1936 the University of Toronto, Messrs. Siemens-Halske of Berlin, the Radio Corporation of America, the General Electric Company and, in this country, the Metropolitan-Vickers Electrical Company, have produced rather more compact instruments which are relatively simple to operate and are capable of giving magnifications up to 50,000 diameters. The latest Metropolitan-Vickers model, the EM.3, is illustrated in Fig. 6.

Construction and Operation

Fundamentally all electron microscopes consist of four elements—the vacuum system, the electrical

to the production of contrast in the photographic image. Since the electrons after collision are not only reduced in velocity, but are " scattered " it follows that they will not be brought to a focus with the unscattered electrons on the photographic plate. They will, in fact, be brought to a focus in front of the plate and will then reach the plate, producing a fine fringe round the image. This is in fact the origin of the thin white border that is seen, surrounding the positive enlargement of an image photographed by the electron microscope (see Fig. 3, which is an electron micrograph of magnesium oxide smoke magnified 55,000 diameters).

In the microscope made at Toronto University, use was made of a small aperture, placed below the pole-pieces of the electron lens. As indicated in Fig. 4, the effect of this is to cut out a larger number of the slower moving electrons, and these being absent in the final image increase the contrast there.

Fig. 5.—Diagrammatic arrangement of the electron microscope built by Knoll and Ruska in 1932.

Fig. 6—The Metropolitan- Vickers EM.3 electron microscope.
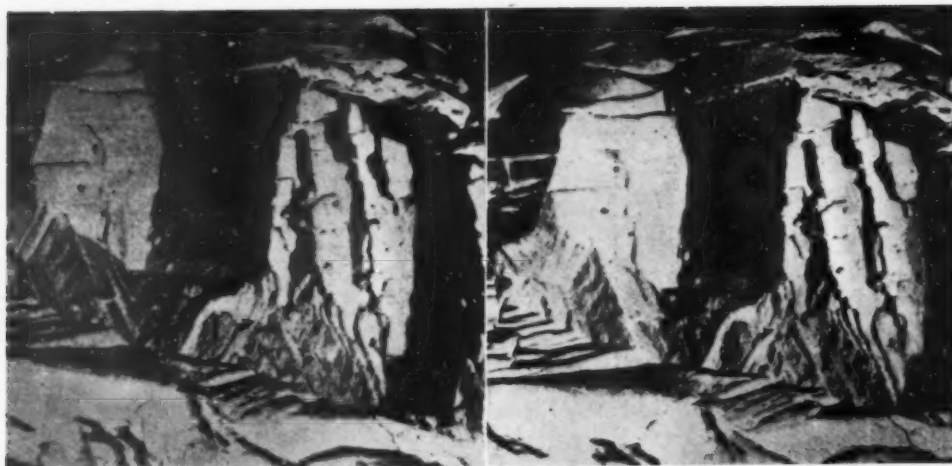
Fig. 7.—Electron stereo-micrograph of an etch pit in pure zinc.
× 8,000.

system, the electron optical system and the control system. The function of the vacuum system is, of course to evacuate, and maintain the vacuum in, the electron-gun tube. The degree of vacuum required is of the order of one-millionth of a millimetre of mercury. The electron gun, which really consists of the perforated anode and the coils for accelerating and concentrating the stream of electrons, is contained in a tube usually made of glass. Into the top and bottom are sealed the cathode and the anode. When the cathode is of the " hot " type, the high tension of the direct current source is connected to the cathode while the anode is earthed. Surrounding the space between the anode and the cathode is a cylindrical shield, the purpose of which is to prevent the escape of stray electrons and to absorb the X-rays produced at the anode.

The object to be viewed must be specially prepared The ordinary glass slide used in light microscopy is unsuitable because the mount must be completely transparent to the electron beam. A very thin plastic film is a suitable mount provided the thickness is in the region of one millionth of a centimetre. Such a film can be produced by allowing one drop of a two per cent. solution of collodion in amyl acetate to fall on to the surface of clean water contained in an eight-inch diameter cylindrical vessel. The drop quickly spreads itself over the surface of the water to within half-an-inch of the edge of the vessel. After a short interval the solvent acetate will have evaporated leaving a film of the right thickness on the water. In use such a film is usually supported on a 200 mesh copper grid. So a number of such small grids are placed on the floating film and then the film and grid are lifted up together by a special tool. These prepared films are stored in a desiccator until required for use.

The specimen is placed in the microscope below the condenser lens and immediately above the object lens. It is inserted through an air-locked opening in the side of the tube, and this arrangement obviates the necessity of letting the tube " down " every time a specimen is changed.

The electron optical system consists of the objective and projecting lenses. The former produces an image of the object at a position indicated in Fig 1, and labelled first image. This image is received on a fluorescent screen suitably placed and is visible to the operator through an eye-piece located in the side of the microscope. The degree of magnification at this stage is about 100 times. A small central hole in this first screen permits a small portion of the electron beam to pass through to the projector lens. In this way a small part of the first image is further magnified up to about two hundred times, and can be received on the second screen at the position labelled 2nd image, or it can be photographed on a film or plate. When photographs are to be made the final magnification is conveniently arranged to lie between five and ten thousand times ; since in this range the field is larger and the image intensity is greater than at higher magnifications. The resolution is usually such that the photograph can be usefully enlarged from twenty to ten times according to the original magnification.

On account of the very small aperture of the objective system, the depth of focus in all electron microscope photographs is very large. In fact this tends to give a three-dimensional effect. Where, however, a decided three-dimensional effect is required to provide additional information stereo-pictures can readily be made. In the R.C.A. model a device is provided which enables the specimen to be tilted at a small angle to the normal right and left. A picture is taken with the specimen tilted in one direction, after which the specimen is tilted in the opposite direction and another picture taken. On development a pair of stereo-pictures is obtained, and these, when correctly spaced and examined through a stereo-viewer, show a pronounced depth of focus. Fig. 7 shows an electron stereo-micrograph of an etch pit in pure zinc magnified 8,000 diameters.[*]

Replica Technique

The method of preparation of specimens for examination is usually accomplished by putting a drop of a dilute aqueous solution of the substance in question upon the prepared film. After evaporation sufficient substance remains upon the film and its suitability for examination by the electron microscope can be verified by viewing it in an ordinary optical microscope. But as even the thinnest films of most solids are opaque to electron beams, it is not possible to examine directly the surfaces of solids. Until comparatively recently the only means of examining the polished and etched surfaces of metals was by employing the optical microscope using reflected light. This method is not applicable to the electron

[*] J.O.S.A. **35**, 146, 1945.

positive or double transfer method. The first method consisted in coating the etched surface with a solution of collodion in some suitable solvent. After the volatile solvent had evaporated the separation of the film and the metal was effected by dissolving the metal in an acid This had the disadvantage of destroying the original specimen, besides raising doubts about the accuracy of the negative after such treatment. An alternative method consists in dipping the specimen in a solution of polyvinyl chloride in ethylene dichloride, and allowing it to dry with the prepared surface vertical. The draining of the solution results in a thicker coating appearing at the lower edge of the surface. This is, indeed, strong enough to be manipulated with tweezers, and so the replica can be peeled off. When suitably supported on copper gauze the negative can be examined.

The double transfer method consists in first making a negative and from this a positive. The first or negative replica can be made using *polystyrene* and from this a silica positive. The R.C.A. have worked out another method which consists in evaporating metallic silver on to the surface to be examined. This is best done in a vacuum. Then this thin film is reinforced by a layer of silver deposited electrolytically. When the film has sufficient mechanical strength that it can be stripped off, it is removed and treated with a solution of collodion. In this way a positive is obtained, after the silver has been dissolved away in nitric acid. Fig 8, shows an electron micrograph of a silica replica of polished and etched stainless steel† (1945).

Fig. 8.—Electron micrograph of a silica replica of polished and etched stainless steel. X 8,000.

beam. But an alternative has been devised and the replica method is now used. There are two types of replica –the negative or single transfer method and the

† *Metallurgia*, **34**, 1946, p. 184.

Science and the Steel Foundry Industry*
Core Bonding Materials

A further conference held at Ashbourne Hill, Leamington Spa, organised by the Steel Castings Division of the British Iron and Steel Research Association for the steel founders was concerned with core-bonding materials, and several papers were presented for discussion, brief summaries of which are given in this report.

D<small>R.</small> W. J. REES, chairman of the conference on the above subject, welcomed members present, especially those not concerned normally with the iron and steel industry. The purpose of the conference was to bring together founders and producers of core bonding agents in order : (*a*) to focus attention on work done and which perhaps had not yet been applied as fully as it might be, and (*b*) to direct attention to fields where further work might usefully be carried out.

The first paper was by PROF. T. P. HILDRITCH, F.R.S., who reviewed the natural drying oils in which he first discussed the linoleic and linolenic acids, which, as glycerides, gave linseed and other drying oils their desired characteristics. The linoleic has two double bonds in the molecule, the linolenic, three. Oils rich in glycerides of the former are slower to autoxidise and polymerise, while those rich in the latter are quick drying. Linseed oil is a typical example of one rich in

* Continued from December 1948, Page 113.

linolenic glycerides. In a table giving a number of vegetable oils with linoleic and linolenic data it is shown that conopher, candlancet, rubberseed and perhaps stillingia are possible alternatives to linseed oil, but Prof. Hildritch thought castor oil the most likely substitute.

The theory and practice of bonding was discussed by D<small>R.</small> J. WHITE who described some of the work at Sheffield University, sponsored by B.I.S.R.A. He described green and dry strength tests and various methods of assessing plasticity. Strengths given by oils under test were compared along with the strength given by linseed oil as a standard. But other materials, such as urea formaldehyde should be compared in the complete binder with the linseed containing binder at something like the same green strength. Dr. White said that in measuring dry strength it was generally found that there was an optimum temperature and an optimum drying time. Below this temperature the necessary time was too long, and above it maximum strength

was not reached. With linseed oil, taking 2% at 200° C., a strength of 390 to 400 lb./sq. in. was reached in 2 hours. At 170° C. the rate of hardening was slower and at 240° C. the maximum strength was reached sooner but was less. Castor oil developed maximum dry strength after a rather longer period than linseed required— 3 hours with 2%. It seemed significant that linseed oil films appeared to be much more elastic than any of the others tested. Tung oil had been disappointing. It had given a reasonably good bond, but had only three-quarters of the strength of linseed for a given content. Tall oil and soya bean oil, on the other hand, gave low strengths at 2% but improved as the content was increased. Soya bean oil at 3% gave actually higher strength than linseed oil. Information was also given on several synthetic resins which had been tested.

In a paper on plastic materials as bonding agents, Mr. J. M. J. Estevez said he thought synthetic resins held out considerable promise, but development work was still required before their full advantages could be reaped. Two types of thermosetting plastics were used for core bonding: urea formaldehyde and phenol formaldehyde. Unfortunately, these terms were about as imprecise as the term " iron." All urea formaldehyde resins and some phenol formaldehyde resins could be set rock hard in the cold by the aid of an acidic catalyst, but it was usual to employ heat for speed and control in making cores. On heating or " curing," the organic matter, mixed intimately with the sand, undergoes a sudden transition to a continuous solid mesh structure of an infusible material which binds the sand into a coherent whole and evolves a small amount of steam. This was in distinction to the action of linseed oil which becomes solid through uniting with oxygen of the air, slowly and over a range of temperatures.

Synthetic resin bonded cores thus reach maximum strength in from one-half to one-quarter the time required by a linseed oil bonded core, and at about 160° C. and about 200° C. for urea and phenol formaldehyde respectively. Urea formaldehyde should not be heated for longer than necessary to give full "cure," but with phenol formaldehyde little or no deterioration results from an excess of heating time.

Mr. Estevez said it was agreed that, generally speaking, urea formaldehyde was mainly useful for core bonding for aluminium, magnesium and their alloys, though it was also useful in ferrous work where the metal section was very thin. Phenol formaldehyde was generally claimed as useful for brass, bronze, iron and steel foundries. There were two main types, one a liquid and the other a solid. It is possible that a mixture of from 3 to 5 parts of the solid with 1 to 2 parts of the liquid would draw a happy balance when used in the usual proportion in the total mix.

Petroleum derivatives were next discussed by Dr. H. K. Whalley who said petroleum aromatic extracts had been used for some years as a partial replacement of linseed oil, with reasonable satisfaction and economic advantage. There are three main categories of components of crude petroleum : the paraffinic compounds, straight chain carbon atoms ; the naphthenic compounds which were rings, fully saturated ; and the aromatic type fully saturated with hydrogen all the way round. Complex combinations of these intra-molecular blocks are encountered, of which a simple example would contain a naphthene ring, an aromatic ring and various side chains. The refiner had to produce from " this

incredible mixture " lubricating oils, transformer oils, etc., leaving the various extracts which different industries require. Distillation is the first stage in the separation of these various materials and solvent extraction the second stage. It is the latter stage which is of chief interest to producers and users of core oils. A series of these extracts have been developed for core compounds to meet the various demands of the industry. Their cost is about one-eighth of that of linseed oil and as a result of close and continuing co-operation between the oil and foundry industries, the contribution of the oil industry is giving satisfaction to the user.

A paper on gases evolved from cores, given by Mr. W. M. Lord, was the first presented at a second session in which he stated that there were four overlapping stages at which gases, vapours, or fumes might be evolved : (1) During mixing, etc., up to insertion of the core in the oven ; (2) during the baking process ; (3) after removal from the oven and while cooling ; and (4) during and after casting.

The most troublesome fumes with which the foundry-man had to deal were evolved during and after casting. Both for their effects on human vitality and on the quality of the castings it was desirable to reduce fume and gas evolution as far as possible. As the fume was often produced from a number of moulds arranged over a considerable floor area the problem was a difficult one. Only in certain mechanised plants could moulds be passed through a cooling tunnel under exhaust conditions. In a foundry producing jobbing work, little could be done except to localise casting to one part of the foundry with a good exhaust system. The fundamental method of attack on the problem was the production of binders which did not produce noxious fumes. On this point Mr. Lord asked manufacturers of core binders to " investigate the important matters of fume production and composition with a view to offering to the trade tested materials which are not objectionable and not injurious to the health and well-being of all who work in foundries."

Application of New Materials

The application of new materials to core binding in the steel foundry was next considered in a paper by Mr. H. E. Crivan, who described his experiences with various core binders, most of which were of the semi-oil type with a substantial proportion of clay bond. A brief summary of the results of his experiences will be of interest. He has used castor oil successfully for very light castings, the only disadvantage being the strong odour. Tall oil he found satisfactory for replacing linseed type oil for light and medium weight castings. the only disadvantage being the strong fish-like odour. Stryrene co-polymer medium, used for medium weight castings, gave friable cores in a semi-oil sand mixture after baking, rendering it liable to cause scabbing. Urea formaldehyde beetle resin, used in straight-oil-sand mixture, gave satisfactory results for very light castings. Its disadvantages are a strong fish-like odour and a rapid drying out on the core bench. Plastic resin (LRX1022), used with cereal on a 50/50 basis, gave good results in light castings. Providing this resin is available, Mr. Crivan thought there were no practical objections to its use in the steel foundry.

In discussing core binders for the iron foundry, Mr. E. C. Dickenson said that during the inter-war

years the most important material used was linseed oil, with the addition of cereal binders such as dextrin and starch, or of viscous fluids such as molasses and sulphite lye. The selected drying temperature had to be a compromise between the ideal temperatures for the ingredients. The present shortage of core bonding materials had led to experiments with many substitutes with reasonable success, though none were so good as linseed, and some were more critical to temperature and time of baking. His own foundry used an aromatic petroleum residue to take the place of one-third of their linseed oil in their linseed-molasses mixture, which developed dry strength at not below 475° F. He thought there were possibilities in the thermo-setting resins such as urea and phenol formaldehyde, but something would have to be done by the organic chemists about their " ancient and fish-like smell." They were, because of their trigger action in setting, admirably suited for baking by the high-frequency dielectric loss method, and many of the larger iron foundries were experimenting along these lines.

Mr. G. L. HARBACH in his paper on the use of synthetic resin core binders in non-ferrous foundries described development work that had been sponsored during the last two years by the Joint Standing Committee on Conditions in Iron Foundries, and also by the Technical Committee of the Association of Bronze and Brass Founders.

From the point of view of baking strength and temperature the synthetic resins appeared to have advantages in fuel saving. The proportions of various bonding materials required to give a tensile strength of 250 lb./sq. in., after baking for one hour at various temperatures, were :—

    Semi-solid oil binder .. .. 4% (210/220° C.)
    P.F. resin liquid .. .. 3% (160° C.)
    Linseed oil .. .. 1½% (as semi-solid)
    U.F. resin liquid .. .. 1⅜% (175° C.)

Mr. Harbach thought that synthetic resins provided an alternative to oil bonded sand in the matter of dry strength with advantages in production time and fuel consumption, but further development work was necessary to produce the desirable adjustment for green bond with flow ability and non-stickiness and a balanced speed of air drying. Phenol formaldehyde resin appeared to be the most promising for general work, as surface finish and breakdown temperature were equal to those of oil bonded sands. Further, the fumes were far less objectionable than the fumes from the core binders most commonly employed.

Mr. W. M. Lord discussed core bonding practice abroad in which he mentioned substances used in Germany, such as tall oil fatty acids esterified with glycerol or penta-erythritol at 280° C. ; another ester formed by reacting tall oil acids with acetylene to produce the vinyl ester sold as Lumitol ; sulphate cellulose lye in liquid or dry powder form, with addition of urea formaldehyde resins, and an addition of 5 to 15% of urea itself to a waste sulphate liquor, which gave promising results ; methyl cellulose and cellulose glycollic acid were used during the war, sometimes with a proportion of synthetic resin to give improved dry strength. American claims were made that thermo-setting corebinders had been introduced into the foundry nearly 27 years ago, and had been used to advantage both in light alloy and ferrous work. Other materials in which interest is maintained are : aqueous solutions of cresol or xylenol ; partly condensed syrupy Bakelite ;

a petrol insoluble pine wood resin cooked with drying oils and emulsified in water containing casein and ammonia. In Switzerland, good results had been obtained with melamine-formaldehyde resins.

Mr. Lord was of the opinion that cellulose derivatives, having good green strength and little gas evolution, and being clean to handle might be worth more investigation to improve the dry strength. He thought the organic silicon compounds might provide good core binders in the future.

A demonstration and talk on dielectric loss heating and its possible future application in the foundry industries was given by Mr. C. E. TIBBS. He said that the principle of this form of heating was that the material (a non-conductor of electricity) to be heated is placed between the two plates of a condenser, there it is subjected to rapidly-alternating electrostatic stress which develops heat by molecular friction. Mr. Tibbs gave a convincing demonstration with a urea core sand mix that he pressed into an ash tray and baked perfectly hard in 2½ minutes. During the demonstration it could be seen that the power fell off substantially as the curing proceeded, a feature that was claimed to obviate any danger of overbaking. After discussing various American installations and British possibilities, he estimated the overall cost of a unit to deal with about 15 cwt. of cores per hour (over a period of ten years for writing off the capital cost) at about 11/- to 15/- per ton.

Tufra-red heating by electricity and by gas, respectively, were discussed by Mr. J. C. LOWSON and Mr. A. C. JENNINGS. Tufra-red or medium temperature radiant heating was introduced into this country during the war, using both forms of heat. The process could not be used successfully for cores and moulds with deep crevices or narrow slots, nor could it dry thick cores right through in a few minutes. But the process has been successfully applied to the drying of small, thin cores and to the skin drying of large cores and moulds, as long as they did not have too complicated a surface.

The last paper before the conference was on core blowing, it was given by Mr. W. WEST who contrasted the British approach—horizontal blowing, confined to " sausage cores : round, plain, easy jobs "—with the American method of vertical blowing, where "no matter how intricate the core is, you can, by suitably splitting up the core box, produce satisfactory cores at low cost."

Some examples of cores blown at Leyland Motors were shown by Mr. LORD who emphasised the necessity of adequate venting. He said that in the U.S.A. even small foundries have small bench machines, and use them for even 20 off. The objections now raised against core blowing had been raised against moulding machines which were now generally accepted. Core blowing machines also gave a more consistent and controllable result than hand work. This the speaker regarded as a matter of great importance, and suggested that B.I.S.R.A. might organise another conference on the subject of core consistency.

Nichrome

Nichrome is familiar to Metallurgists as indicating a particular range of nickel-chromium alloys, it is, of course, the registered trade mark of British Driver Harris Co. Ltd.

Copper and Copper Alloys[*]

Technical Progress in 1948

By E. Voce, Ph.D., M.Sc., F.I.M.

Copper Development Association

Much development work in the production and application of copper and its alloys has been accomplished or put into operation during the current year, some of the more important aspects of which are given in this review. More copper ore deposits have been reported and reference made to interesting plant and manufacturing technique. Particular attention is directed to foundry progress and to the new British Standards Schedule of Copper Alloy Ingots and Castings ; fabrication technique ; plating and finishing ; properties of copper and copper alloys ; corrosion ; and analysis and testing. Although it has not been possible to review all the fields of activity, sufficient is given to indicate that the year has been a fruitful one and has brought advances in practically every branch of industry.

Plating and Finishing

Sodium-hydride Pickling.—An open discussion on scale removal under the auspices of the Birmingham Metallurgical Society[48] provided, among other information, a detailed account of descaling by means of sodium hydride. Sodium hydride, prepared *in situ* in a bath of molten sodium hydroxide, has the power of reducing the oxides of most metals, including the copper-base alloys, leaving a loose superficial layer of the reduced metal which can afterwards be removed by any convenient means. The action is rapid and, as the basis metal is entirely unaffected, overpickling is impossible. A fuller account of the process, including operative details, with special reference to copper and its alloys, has been published by Alexander.[49]

Electrolytic Polishing.—Until now it would have been true to say that the electrolytic polishing of copper and its alloys had not yet reached industrial importance, at any rate in this country. Recently, however, a publication by Berger[50] describes the development of a full-scale plant for the electrolytic polishing of brass pressings. As a result of considerable experimental work the following complex electrolyte was adopted :—

Water	.. .. ..	70–90%
Phosphoric acid	..	10–30%
Chromic acid	.. ..	180 gm. per litre
Sodium dichromate		420 gm. per litre
Sulphuric acid	.. ..	80–95 gm. per litre
Hydrofluoric acid	..	3–6 gm. per litre
Propionic acid	.. ..	80–150 gm. per litre

At an anode current density of between 140 and 350 amps/sq. ft., with temperatures from 60°–120° F., about four minutes are normally required to produce a good polish on small articles, though it is admitted that less success can be achieved with large, flat surfaces. A modified electrolyte is necessary for polishing leaded brasses.

Other methods for the electrolytic polishing of copper and its alloys are outlined by Wernick[51] in his valuable book on the electrolytic polishing and bright plating of metals.

Electroplating.—In the realm of electroplating, as distinct from electrolytic polishing, increasing attention is being paid to the new process in which the current is reversed periodically for a short time.[52, 53] Smoother and sounder deposits are claimed, and the method is said

to be particularly suitable for thick, dense deposits of copper as well as for bright brass plating. Higher current densities may be used so that plating time is shortened despite the periodic deplating. Both Schore[54] and Van der Sommen[55] deal with the electrodeposition of copper from acid-sulphate solutions, with particular reference to the effects of organic additions on the smoothness of the coating and the stresses produced within it, while Thews[56] has contributed an informative series of articles on anodes for electroplating. He stresses the fact that deoxidized copper is preferable to tough pitch for this purpose.

Two new books on electroplating, by Ollard and Smith[57] and by Silman[58] respectively, should be mentioned.

Properties of Copper and Copper Alloys

Creep and Fatigue.—As information on the creep characteristics and fatigue properties of wrought copper-base materials has been, until now, exceedingly scanty, contributions by Burghoff and Blank[59, 60, 61, 62, 63], covering these subjects in very considerable detail are particularly welcome. In these brief notes it is quite impossible even to summarise the extensive data they have compiled in a long series of researches culminating in papers published recently, but the wide scope of the work is evident from the fact that they investigated the creep properties of four different coppers, five brasses, a phosphor bronze, a silicon bronze, a cupro-nickel and two copper-nickel-phosphorus alloys, one of which contained tellurium. Each material was tested in several different degrees of cold work and with various grain sizes, while temperatures of 300°, 400°, and 500° F., were employed, with an appropriate range of stress at each temperature. In all, well over 500 individual creep tests were carried out and data for initial extension, creep rate and stresses corresponding to creep rates of 0·001, 0·01 and 0·1% per 1,000 hours are recorded.

The two papers concerned with fatigue[62, 63] deal respectively with material in rod and strip form, and cover an even wider range of alloys than those used for the creep tests. For the experiments on strip, three coppers, seven brasses and two tin bronzes were used, while the tests on rod embraced two coppers, nine brasses, four silicon bronzes, a cupro-nickel, an aluminium bronze and three special copper-nickel-phosphorus alloys containing tellurium. For both sets of experiments the fatigue strengths for 100,000,000 cycles lay between

about 20 and 50% of the tensile strength, the majority being in the region of 30%. As a broad approximation it would appear, therefore, that for a large number of copper-base alloys the fatigue strength is about one-third of the tensile strength.

Gohn and Ellis[64] have reported fatigue tests on hard-rolled 18% nickel silver and spring-temper phosphor bronze containing 8% tin. To simulate conditions in spring contacts, for which these alloys are widely used, the stresses though fluctuating, were always applied in the same direction. Under these conditions it was found that the range stress which could be endured was constant, irrespective of the mean stress, provided that the yield-point of the material was not exceeded.

High-strength High-conductivity Alloys.—Two new high-strength high-conductivity alloys suitable for stranded electrical cable have been developed by the Batelle Memorial Institute.[65, 66].

The first of these consists of copper with from 6–7% of silver.[65] By a judicious introduction of heat-treatment into the wire-drawing schedule, tensile strengths up to 73 tons/sq. in. or more, with conductivities of over 70% I.A.C.S., can be achieved. The ductility is sufficient to make stranding possible. The percentage of silver named approaches the solid solubility limit in copper under equilibrium conditions, though much remains as a separate phase in cast structures.

Nearly as strong, though of somewhat lower conductivity, are alloys of copper with between 10 and 15% of iron and from 0·03–0·10% of magnesium.[66] Alternate drawing and heat-treatment lead to tensile strengths of from 67–72 tons/sq. in. with electrical conductivities of 55% I.A.C.S. or more. The primary dendrites of iron elongate into strong threads during drawing, while the object of the heat-treatment is to precipitate iron from solid solubility in the copper with consequent improvement of conductivity.

Cadmium Copper.—A new investigation by Raub[67] shows that the solubility of cadmium in solid copper increases from about 1·0% at 350° C., to 4·5% at 650° C. With further increase of temperature the solubility diminishes gradually and becomes zero at the melting point of copper, 1,083° C. The form of the curve suggests possiblities of precipitation hardening, especially in the case of alloys containing rather more cadmium than that usually present in commercial cadmium copper.

Alloys of Manganese.—The extensive researches of Dean[68] and his collaborators on the constitution and properties of copper-base alloys containing electrolytic manganese have continued, and the properties of certain ternary copper-manganese-zinc[69] and copper-manganese-aluminium[70] alloys have been described. It is claimed that the addition of manganese to brasses in the alpha range increases the tensile strength by about half a ton per sq. in. for each 1% of manganese without detriment to the ductility, though the mechanical properties attained are not particularly attractive. In the copper-manganese-aluminium system the strength is primarily controlled by the aluminium content, and manganese has relatively little effect. The constitution of the aluminium-rich alloys in this same ternary system has been studied by Day and Phillips.[71]

Dean[72] has also examined the straight copper-manganese alloys, with their well-known combination of high-specific resistance and low-temperature coefficient. Alloys prepared from electrolytic manganese and electrolytic copper were hot-worked without difficulty

and after soaking at temperatures within the single-phase solid-solution range could be cold-worked by rolling, swaging, and drawing. For alloys containing between 60 and 70% of manganese when quenched from 800° C., the temperature coefficient was zero, while the resistivity reached its highest value of 188 microhms per cm. per sq. cm.

The abnormally high-damping capacity of the copper-manganese alloys makes them suitable for structural materials in cases where vibration is involved.[73]

Beryllium Copper.—Beryllium copper continues to excite scientific as well as technical interest, and both Forsyth[74] in this country and Hunger[75] with others in Germany have studied the rate and mechanism of precipitation of the gamma phase at the grain boundaries during the hardening treatment. The electron microscope indicated that decomposition of the beta phase into alpha and gamma commenced at 450° C. This is considerably above the temperature at which hardening is effected in normal practice by the separation of gamma from the alpha solid solution.

Copper in Cast Iron and Steel.—A remarkably fine book on copper as an alloying element in steel and cast iron has appeared under the joint authorship of Lorig and Adams[76] who have well achieved their object of providing an up-to-date and critical survey of the technical literature of the subject. Although the evidence appears to have been reviewed impartially, there is hardly a page on which some advantage or other of the use of copper is not manifest, one of the most frequently recurring being the improved ratio of yield-point to tensile strength. Not only is the book invaluable for reference purposes, but it will undoubtedly re-awaken the interest of manufacturers and users alike in these highly attractive alloys.

Corrosion and Surfaces

Stress Corrosion Cracking.—An admirable review of the incidence of stress corrosion cracking in copper alloys was presented by Cook[77] to the Institute of Metals in connection with their recent Symposium on Internal Stresses. The available information indicates that stress corrosion cracking is found in alpha brasses containing over 15% of zinc, but that copper and other copper alloys are relatively immune. Chaston[78, 79] also discusses the same subject and gives an authoritative statement on modern views concerning the causes and prevention of stress-corrosion cracking of brass.

Oxidation of Cupro-Nickel.—Continuing their investigations by electron diffraction methods of the nature of the oxides formed on metallic surfaces at elevated temperatures, Hickman and Gulbranson[80] have studied the copper-nickel alloys. At temperatures above about 600° C., nickel oxide was mainly formed, while at lower temperatures cuprous oxide was usually the chief product, though cupric oxide was also found in some cases, especially at temperatures near the transition from copper to nickel oxides.

Analysis and Testing

The Spectrographic Determination of Copper in Copper-rich Alloys.—Up to the present, spectrographic analysis has been accepted as an ideal method for the determination of small quantities of impurities, but has not been considered practicable for the major constituents of alloys, except qualitatively. Spicer[81] has recently described various procedures for the quantitative

spectrographic determination of copper in brasses and cupro-nickels from the ratio of the intensities of a pair of its lines. The method is claimed to be suitable for the determination of copper in the range of from 70–90% in copper-zinc alloys and from 90–99% in copper-nickel alloys.

Stress-strain Relationships under Homogeneous Deformation.—A few years ago the results of Cook and Larke[82] for compression tests on copper alloys carried out under conditions which compensated for the disturbing effects of bulging were published. It has now been shown by Voce[83] that a simple equation connects stress with strain under these conditions, and that the same equation is applicable to tensile tests up to the point at which necking, with its attendant inhomogeneity of deformation, commences. Under homogeneous deformation Cook and Larke's tests indicate that the true stress tends to become asymptotic to a definite fixed stress for large strains, and the difference between any particular applied stress and this final stress can, therefore, be regarded as the capacity for stress remaining available to the material. Voce shows that the rate of change of true (logarithmic) strain with respect to true stress is inversely proportional to the stress capacity at the instant under consideration. While this relationship does not embrace the important effects of temperature and strain rate, it provides a basis for further research.

Conclusion

When it is appreciated that lack of space has prevented mention of numerous papers which, though related to the subject, are concerned less directly with copper and its alloys than those which have been reviewed, it will be apparent that the year has been a fruitful one and has brought advances in almost every branch of the industry.

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Monarch-Keller Form Turning Machine

THE Rockwell Machine Tool Co., Ltd., Second Way, Exhibition Grounds, Wembley, Middlesex, advise that as from January 1st they have been appointed as sole-selling agents in the United Kingdom for the above machine. The Rockwell Company already handle all other Monarch Turning Machines.

The Monarch-Keller Form Turning Machine, previously handled by Alfred Herbert, Ltd., is used extensively in the manufacture of moulds, punches, dies, form rolls and spinning chucks. It is available in a wide range of sizes, which will shortly be augmented by a new large machine specially developed for the steel industry.

Copper and its Alloys in Engineering and Technology

EVERYONE who is associated with the engineering industries, as a student, engineer, works manager, or in purchasing engineering materials, will find much information of practical importance in the Copper Development Association's latest publication, No. 43, entitled, " Copper and its Alloys in Engineering and Technology," which is now available.

The book is in nine sections, and describes in terms which the practical man can understand, the various grades of copper, the alloys of copper and other metals, the brasses, bronzes and gunmetals, and their electrical, mechanical and other properties. A useful series of tables classifies all these materials according to the type of service for which they are suitable. An appendix gives a simple explanation of the metallurgy of copper and its alloys, indicating the changes which can be effected by heat-treatment, and how to make use of equilibrium diagrams.

The book, which is appropriately illustrated, is issued free of charge to applicants giving evidence of responsible status or genuine interest. Applications should be addressed to Copper Development Association, Kendals Hall, Radlett, Herts.

The Use of Inhibitors for Controlling Metal Corrosion

Part II. — Types of Inhibitors

By G. T. Colegate, B.Sc., A.I.M.

The use of inhibitors for preventing galvanic action between dissimilar metals in contact, in the presence of an aqueous medium, is discussed. Reference is made to types of inhibitors, and dangerous and safe ones are considered.

IN the previous article* of this series inhibitors were classified into anodic, cathodic and adsorption inhibitors. Evans[1] describes the anodic type as being in general dangerous inhibitors and the cathodic type as being in general safe ones, the dangerous ones being those that may diminish the rate of attack but increase its intensity, whereas the safe inhibitors are those which reduce the corrosion rate without increasing the intensity. The reason for the distinction is as follows. When a corroding system is partially or fully under cathodic control, the intensity of the attack on the anode is greatly influenced by the relative areas of anode and cathode. Thus, if a large cathode is in contact with a small anode, the attack will be much more intense than if the areas of the two electrodes were equal or if the anode were larger than the cathode. On adding an anodic inhibitor to a system, the anode becomes polarised by the inhibitor and if for any reason, for example, insufficiently high inhibitor concentration, the anode is not polarised over the whole of its area, the net effect will be to reduce the effective anode area with the resulting intensification of attack on the exposed or unfilmed portion. In the majority of cases met in practice this concentrated form of attack is likely to be much more serious than general attack taking place over the whole anode area since it leads to pit formation and rapid penetration of the metal. It is thus quite clearly essential to ensure that the concentration of the inhibitor in the system is always above a certain minimum. If a system is entirely under anodic control, not a very common state of affairs, the anodic inhibitor will no longer act as a dangerous one even if the concentration is insufficient to give a complete film on the anode.

A safe inhibitor, on the other hand, is one which acts on the cathode. In this case, even if the concentration is insufficient to ensure complete polarisation of the cathode, no concentration of attack on either anode or cathode will take place.

Thornhill[2] has shown that even cathodic inhibitors are not always safe. He quotes some work in which he shows that on partially immersed steel specimens addition to the water of certain salts of zinc and chromium, which are cathodic inhibitors, transfers the point of attack from well below the surface to the waterline, and at the same time intensifies the corrosion.

Evans[1] has pointed out a further case in which a cathodic inhibitor may give rise to intensification of attack. For example, in a closed system the total amount of attack may be determined by the amount of oxygen present in the system. Now if part of the system is protected by a film, the amount of corrosion will be the same as if the whole of the metal were unfilmed so that the intensity of the attack on the unprotected area will be greater than if it were spread over the whole surface. This type of phenomenon can occur whatever the type of inhibitor used.

Inhibitors for Preventing Galvanic Action

There are many different types of industrial apparatus in which dissimilar metals are used in contact with each other in the presence of an aqueous medium and in which for one reason or another such contact cannot be easily avoided. In such cases inhibitors are extremely valuable in preventing or minimising the attack. As far as possible, of course, dissimilar metals in contact with each other under corrosive conditions should be avoided or the metals should be chosen in such a way as to ensure that there is no greater likelihood than absolutely necessary of galvanic attack taking place. Insulation of one metal from another can sometimes be employed to prevent galvanic stimulation of attack. In a few cases painting of one or both metals can be carried out, though the anodic member of the couple should not be painted unless the cathodic one is.

Radiator systems of internal combustion engines frequently consist of several different metals in contact with each other and so do many other types of heat exchange system and in many such apparati inhibitors have been shown to be very valuable in keeping the amount of corrosion to a minimum.

As explained in the first article of this series, when two different metals are in contact with each other in an aqueous medium, it is probable that the one will be more cathodic than the other so that there will be a tendency for current to flow and for the anodic metal of the couple to be corroded more than it would have been, had the second metal not been in contact with it and similarly for the cathodic metal of the pair to be less seriously corroded than it would otherwise have been. In many cases, different metals can be connected together in an electrolyte without ill-effects, but in some instances the attack on the anodic member of the couple may be serious. One way of reducing or preventing such attack is by using inhibitors which have been shown to be effective in many cases.

As will be explained in the next article, chromates and dichromates are very widely used as inhibitors for iron and steel, and they are also very effective with other metals such as aluminium and magnesium. It is not surprising, therefore, that chromates and dichromates are also very effective materials for use in combating galvanic corrosion. Both these materials are classified as anodic inhibitors and in bimetallic corrosion they function by polarising the anode, that is to say, by forming a very thin film on the anodic surface and thus effectively preventing, or at least largely minimising, the flow of current by introducing the high resistance of this film into the galvanic circuit. In view of

* *Metallurgia*, Nov., 1948, 18–20.

1 Metallic Corrosion, Passivity and Protection, 2nd Ed., Arnold, 1946.
2 *Ind. Eng. Chem.*, 1945, **37** (8), 706.

the fact that chromates act on the anode, there is always the risk that, if present in less than a certain minimum concentration, they may tend to localise attack on the anode of a couple by forming an incomplete film which is equivalent to reducing the area of the anode so that the whole of the corrosion which occurs as a result of the passage of the current takes place at the unprotected point instead of being spread over the whole anode surface. Such concentration may lead to rapid pitting and perforation. On the other hand, if the amount of chromate is in excess of the minimum required for effective protection, there is no risk at all. In the majority of cases the effective concentration of chromate required to inhibit galvanic attack is very small and the actual concentration can be maintained at many times this figure and still be an economical proposition, so that with reasonable supervision there is little risk in practice of the concentration falling below the point where it becomes dangerous.

The conditions of use, etc., of chromate as an inhibitor for galvanic corrosion are very much the same as for its use in systems containing only one metal, and these are described in the next article of the series. Quantities required will obviously depend on the nature of the two metals under consideration and also on the properties of the aqueous medium, especially on whether or not it contains chloride and, if so, in what concentration.

Iron-Copper Couples

In the iron-copper couple the iron is invariably the anode and under most conditions met in practice chromates are effective inhibitors in preventing or minimising the attack which takes place. A concentration of 0·05% of sodium chromate is usually sufficient to prevent galvanic action between iron and copper provided the chloride content of the water is not high. In many cases, after the initial period of high chromate consumption it is possible to allow the concentration to fall and still maintain complete, or almost complete, immunity from attack. However, unless the system in question is a very big one and therefore justifies regular analytical control this may well prove to be false economy, since failure to hold the concentration above a safe minimum may lead to rapid and highly localised attack as explained above, especially when the area of the copper cathode

is much greater than that of the iron anode.

Iron-Brass Couples

Under many conditions the iron brass couple behaves in a very similar manner to the iron-copper couple, the brass being the anode. The concentration of chromate required to inhibit attack is of the same order as that mentioned in connection with iron-copper couple. Darrin[3] states that for inhibiting galvanic action between iron and brass in brine systems such as used in refrigeration plant, the concentration of chromate should be kept as high as possible. Concentrations of 0·25% or even higher are often needed to prevent serious galvanic action.

Couples Formed by Different Kinds of Iron

It is unusual to encounter galvanic action taking place between two pieces of iron or steel of different composition and in any case such action would not be expected to be serious. However, concentration of chromate such as recommended in the following article for systems composed of one grade of steel only, are adequate to ensure that there is no risk of attack.

Couples Containing Aluminium

When aluminium is one of the metals of the couple chromates are frequently successful in preventing serious galvanic attack. Opinions vary as to the most suitable concentration and this in any case will vary with the couple and will also depend on the environment

The copper-aluminium couple, in which the copper is the cathode, is always likely to give rise to serious corrosion and for that reason is best avoided as far as possible. However, when it is inevitable chromates may be used for mitigating the attack. The concentration required is high and in many cases even 1% of sodium chromate in an aqueous medium is insufficient to prevent the attack entirely. A concentration of 0·1% is sufficient to give some improvement in certain cases but the higher amount is to be preferred. Darrin has shown that the use of sodium metasilicate in addition to chromate gives an appreciable improvement in inhibiting the corrosion of the copper-aluminium couple in tap water. 40 parts per million of metasilicate in conjunction with 500 parts per million of sodium chromate gave better results than when twice this concentration of chromate was used on its own.

3 Ibid, p. 741.

Aluminium coupled to brass behaves in very much the same way as when coupled to copper, and the difficulties of effectively inhibiting this system are the same as for the aluminium-copper couple.

When aluminium is coupled to iron it is not always possible to predict which of the two metals will be the anode and which the cathode. However, the use of an adequate concentration of chromate will usually reduce the attack considerably. Sodium chromate of 0·1% is usually sufficient when the aqueous medium is a water not too high in chloride. With a high-chloride content, however, such as in brines used in ice-making plants, etc., about three times this concentration is required. Darrin states that no concentration of chromate has been found effective in preventing the corrosion or iron or steel in contact with brass in a calcium-chloride anti-freeze solution used in motor-car engines, the temperature of operation being too high (160° F.)

Copson[4] carried out some work on the possibility of inhibiting the galvanic corrosion which takes place between steel and nickel by making additions of chromate and lime. He was able to show that additions of 300 parts per million of sodium chromate to tap water practically completely prevented corrosion, though it was necessary to rub down the steel occasionally in order to dislodge such small amount of rust as had formed, otherwise it was found that pitting tended to occur, thus largely negativing the advantage of the inhibitor.

Lime on the other hand was not found to be a satisfactory inhibitor for the nickel-steel couple as its use results in localised attack on the steel. Sufficient lime was used to bring the pH of the water up to 11·0.

Couples with Magnesium

Siebel[5] considers that a few tenths of 1% of chromate is sufficient to inhibit galvanic attack between magnesium and other metals coupled to it in aqueous media.

Other Couples

Darrin[3] carried out laboratory experiments on the action of chromates on a variety of couples exposed to tap water, and in all cases found that the addition of chromate lessened the galvanic action taking place, though in some instances the attack was by no means entirely prevented. For

4 Ibid, p. 721.
5 Tech. Mag., u. seine Legierungen.

example, galvanised iron in contact with copper, brass or tin showed bad corrosion in the absence of an inhibitor but the presence of 0·1% sodium chromate greatly improved the behaviour of the zinc. Dichromates in equivalent quantity were frequently less effective than chromates in inhibiting the attack between these couples. Iron in contact with tin, and copper connected to tinned iron both showed considerable improvement in behaviour after the addition of chromate.

The effect of silicate as well as chromate additions has been mentioned in connection with the aluminium-copper couple. With certain other couples the simultaneous presence of the silicate with the chromate gave no improvement. This was the case with iron-brass and galvanised-iron-brass couples.

Systems Containing Several Metals Not in Contact

Systems may contain several metals not in contact with each other, so that there will be no question of galvanic corrosion taking place, but on the other hand the choice of inhibitor and the concentration in which it is used must be such as to ensure effective inhibition of the attack on all the various metals. In very many heterogeneous systems chromates are effective as inhibitors.

The use of sodium benzoate, described by Vernon,[6] is an example of a material which can be used effectively in inhibiting the attack on several metals. Unlike chromates, moreover, it is classified as a safe inhibitor so that there is no risk of rapid, highly localised attack taking place in the event of an insufficient quantity being used. Not only is sodium benzoate an effective inhibitor, but it can be used in radiator systems as the antifreezing solution itself, a 30% solution having a freezing point of — 10° C. A solution of this concentration is practically non-corrosive towards iron and steel as well as towards other metals normally encountered in radiator systems, even under the drastic conditions of temperature that exist in such systems.

Inhibitive Pigments

Inhibitive pigments are widely used for incorporating in the first coat of a paint system, that is, the coat which is applied direct to the metal. Several such inhibitors are used in paint primers, both for application to ferrous and non-ferrous metals and they are particularly important in the case of the light alloys based on aluminium and magnesium.

6 J. Soc, Chem. Ind., 947, 66, 137–142.

The best known and most extensively employed of the inhibitive pigments is red lead, which is incorporated in priming paints for iron and steel. The mechanism by which red lead functions, however, is by no means clear, but it is presumably in some way associated with the formation of a soluble lead compound. Nevertheless, though the manner in which red lead acts is not fully understood, its effectiveness as an inhibitor in primary coats has been amply demonstrated, both in laboratory trials and in practice.

Zinc oxide has also been shown to have inhibitive properties when incorporated in a priming paint for steelwork. Ferric oxide is also used as a pigment in such primers, but its inhibitive action is doubtful, though some samples do appear to have a definite influence in preventing corrosion.

The use of chromates as inhibitors in aqueous systems will be discussed in detail in a following article and the mechanism by which they function will be explained. They are also used as inhibitive pigments in paint primers, both for ferrous and non-ferrous metals, though they are generally considered to be much more effective for use with the latter materials than with iron and steel. The indications are that chromates are definitely less effective on ferrous metals than red lead.

The particular chromate used in chromate primers is frequently zinc chromate, since this has a suitable solubility. Obviously, if a very insoluble chromate is used, insufficient of it will pass into solution in any moisture that may reach the metal surface and inhibition will, therefore, not take place. In fact, it is conceivable that as chromates are regarded as dangerous inhibitors acceleration may be the result. On the other hand, too soluble a chromate would be equally unsatisfactory, since it would be rapidly leached out of the film. Barium and calcium chromates have also been used as inhibitive pigments in primers, though they are more often used in admixture with zinc chromate than on their own.

Chromate primers are used very widely for painting aluminium alloys and also for magnesium alloys, it being particularly important in the latter case to have an effective inhibitor in the priming coat. Red lead is never used on magnesium alloys and is best avoided even with aluminium. With magnesium, the pigment should consist entirely of chromate and not be mixed with other less effective materials. Chloride content of the chromate is important and is limited in B.S.S. 389/1938 to 2·5%.

Besides the materials mentioned, several other inhibitive pigments have been investigated. Some of these, such as arsenic compounds, manganese dioxide and magnesia have been shown to have some inhibitive properties, though generally less well defined ones than the substances mentioned above. Metallic pigments such as zinc have also been used and found to be effective, but this is presumably on account of the electrochemical relationship between zinc and iron which results in the sacrificial corrosion of the zinc and the protection of the iron.

Inhibitive Effect of Protective Films

Chromates and phosphates are used in the formation of a variety of protective films on both ferrous and non-ferrous metals, and while in many cases the effectiveness of such films probably depends on their insoluble nature and their complete covering of, and firm adhesion to, the metal surface, nevertheless it is quite possible that in some instances they have an inhibitive function as well.

The use of chromate solutions to "seal" the pores in anodically-formed oxide films on aluminium, and thus increase the corrosion resistance of the film, may also be due in some measure to the inhibitive function of the chromate retained in the pores.

Production of Porous Concrete Using Aluminium Powder

One of the oldest methods of obtaining porous concrete is by mixing aluminium powder with the Portland cement to react with the alkaline compounds and evolve hydrogen gas. Cement treated in this way can be sawn and worked with tools used for wood. Nails can be driven in and facings of cement or plaster applied.

In promoting the reaction, "Standard, unpolished, varnish powder" is recommended for this purpose by Reynolds, who also suggest the following formula for making the product: 1 litre Portland cement, 2 litres sand or sifted ash, 3 grammes aluminium powder, and approximately 1 litre water. Reaction can be hastened by adding slaked lime to the aluminium powder.

Revue de l'Aluminium 25, No. 146, p. 228, July-August, 1948. From *Light Metals Review* 7, No. 23, 452

Reviews of Current Literature

Corrosion Handbook

By Uhlig, H. H. (Sponsored by the Electrochemical Society, Inc:, New York, N.Y.), 8vo, pp. xxxiv+1188. Illustrated. New York, 1948: John Wiley and Sons Inc. London: Chapman and Hall Ltd. Price 72s. net.

In some respects this book is a remarkable achievement. It is the result of a collaborative effort on the part of the Corrosion Division of the (American) Electrochemical Society to compile a convenient reference volume covering the entire field of corrosion. The Division, which was formed in 1942, made this one of their first objectives, as they felt it would serve a useful purpose to bring together much of the information scattered throughout the scientific and engineering literature. The results of this laudable enterprise will bear further fruit inasmuch as the Electrochemical Society has decided to devote the proceeds of royalties on the sale of the book to furthering similar activities in corrosion research.

Although the first section of the book is allotted to Corrosion Theory—we note here a brief but clear exposition of corrosion mechanisms, including the electrochemical theory, by our own Dr. U. R. Evans—this is relatively short and the main emphasis in the book is on quantitative information, mostly obtained as a result of field exposure or service tests. The classification of corrosion phenomena is a difficult matter. Either or both of two methods is generally adopted, in one case according to the corroding metal and in the other according to the corrosive medium. Dr. Uhlig and his colleagues have attempted a compromise; in some sections the classification is by metal or alloy, in others by the corrosive environment. The scope of the work will be most readily appraised by giving the section headings, which are as follows:—

I—Corrosion Theory.

II—Corrosion in Liquid Media, the Atmosphere, and Gases.

III—Special Topics in Corrosion.

(This includes corrosion by sea-water, by soils, and by natural waters, corrosion-fatigue and numerous other topics).

IV—High-temperature Corrosion.

V—High-temperature Resistant Materials.

VI—Chemical-resistant Materials.

VII—Corrosion Protection.

VIII—Corrosion Testing.

IX—Miscellaneous Information.

Within this framework no fewer than 142 separate articles by 103 different authors deal with specific aspects of the subject; for example, to select five at random, " Stress-corrosion Cracking in Stainless Alloys " (M. A. Scheil), " Porcelain " (J. A. Lee), " High-temperature Corrosion of Iron and Steel " (J. B. Austin and R. W. Gurry), " Phosphate Coatings " (V. M. Darsey), and " Soil-corrosion Tests " (I. A. Denison).

It is difficult to assess fairly and accurately the merits and demerits of a book such as this, since so much depends upon the personal reactions of the reader. The writer of this review will, therefore, content himself with enumerating some of the salient good features of this work and then some of its imperfections, as they appear to him.

Merits

1. This is one of the first occasions on which a team of scientific and technical men has deliberately set out to survey in detail such a wide field of knowledge. The whole undertaking must have involved a great deal of organisation and considerable enthusiasm on the part of individual members of the team. In the main our American colleagues may be adjudged to have succeeded admirably in their joint enterprise and are to be congratulated on the results of their endeavours.

2. The book will undoubtedly serve as a most valuable and comprehensive work of reference. It brings into a common pool not only the results of published scientific work but also a mass of technical information and practical experience made available for the first time by individual authors.

3. It focusses attention in an effective manner on the vast amount of work on corrosion or protection that has been completed or is in progress in the United States.

4. Some sections break entirely new ground, more particularly perhaps Section VI on chemical-resistant materials, which should prove extremely helpful to those confronted with corrosion problems in the chemical industry. Moreover, a series of papers dealing with non-metallic materials and semi-metals—e.g., carbon, graphite, porcelain, plastics, boron, and silicon, has quite properly been included in Section II, for, although such materials do not deteriorate by corrosion proper, their potential practical usefulness in corrosive environments was rightly held to justify reference to them.

Demerits

The writer feels diffidence in alluding to what in his view are defects in an otherwise admirable work, because he is conscious of having committed most of the same errors in the past and is not so conceited as to imagine that he will avoid falling into at least some of them again in the future. However, although *nihil nisi bonum* is a valuable precept within its original context, it is not the correct attitude towards scientific work which lives by and thrives on constructive criticism. Consequently, even at the risk of a *tu quoque*, the following points are advanced. Some of them are not limited to the work under review and have a more general application.

1. Synoptic works by many authors have certain undoubted advantages; for instance, if the authors are carefully chosen, their very multiplicity ensures that each particular section is written by an authority on the branch of the subject concerned. On the other hand, they are liable to suffer from a number of serious weaknesses. These include, to mention a few, lack of uniformity in emphasis, style and presentation; inability to view the field as a whole and present the component parts in their correct perspective and true relative importance; unnecessary prolixity; avoidable duplication of statement and overlapping; and, strangely enough, the omission on occasion of vital matter.

2. To deal with the last point first, the most striking instance of it known to the writer occurs in a work of a similar type, " Protective and Decorative Coatings," written by several American authorities on paint technology under the general supervision of that lion-hearted and very lovable man, the late Dr. J. J. Mattiello. It is an astonishing fact that, whilst whole sections of the work are devoted to detailed discussions of drying oils of secondary importance, such as cashew nutshell

liquid, there is no chapter devoted to linseed oil, the backbone of the paint industry.

There are no lacunae of this magnitude in the work under review, but there are a number of minor gaps. On first scanning the book the impression might be gained that references to some important British publications are missing but, in the absence of an author index—a serious defect in any scientific work—it is difficult to check this. In fairness to the authors, too, it should be borne in mind that the book must have taken considerable time to pass through the press, so that the latest references to foreign journals carry the date 1944. Prior to this, the interchange of information was appreciably impeded by wartime conditions. As Dr. Uhlig writes in his introduction : " The times during which the project was organised and prosecuted were not the most favourable for an undertaking of this kind, but postponement seemed less justified than an attempt to do our best under the circumstances." On the whole, it is fair to say that in general the American authors are at least as familiar with British work as we are with theirs.

3. The book runs to 1,188 pages, including the index but not the *prelims*, and weighs just under 4 lb. ; in other words, it is a large and heavy book. (Evans's " Introduction to Metallic Corrosion," for instance, contains 211 pages plus *prelims*, and weighs 15 oz.). The question naturally arises : " Is this length necessary ? " The answer is that by judicious pruning and editing it should have been possible to compress the work by something like 10–20%, without any serious loss of important matter and indeed with marked advantage to its readability, efficiency and attractiveness. Without wishing to give offence, there are occasional places where the work comes perilously near to degenerating into a mere catalogue. One has the feeling, perhaps wrongly, that whole pages of tables have been bodily transferred from, say, the Proceedings of the American Society for Testing Materials.

4. As examples of this diffuseness or imperfection of treatment, the following will suffice :—

(a) p. 243. The text states that sulphur dioxide, ammonia, natural gas and CCl_2F_2 cause no corrosion of magnesium alloys. Immediately below this statement a Table is added in which the corrosion rate of magnesium alloys in each of these gases is solemnly shown as 0·0 mdd (milligrams per square decimeter per day) and 0·0 ipy. (inches per year).

Incidentally, this is the appropriate place to remark that, with all due deference to our American friends, inches per year is not a good unit in which to express corrosion rates. It leads in many cases to the unnecessary and confusing use of a large number of ciphers before the significant figures. Mils. per year, which is a one-thousand times smaller unit, is much more suitable. Its use instead of ipy. would have saved the equivalent of something like 500 ems in the Tables alone contained in the first 100 pages ; this corresponds to from one to two pages on the whole book.

(b) pp. 686–692. Results for the metal loss by oxidation of high-nickel chromium- (iron) alloys are presented in the form of triangular diagrams. The same data are then shown in the form of nomographic charts. Strictly, one or other of these methods of presentation is redundant. If it were desired to retain the triangular diagrams, in order to portray the general effect of nickel additions on the behaviour of iron-chromium alloys, this could be done without loss of clarity by truncating the diagrams

at 40% chromium instead of 60%, as at present (there are no data for alloys containing more than 36% chromium), reducing them in size by one-quarter and printing them the other way up ; they would then occupy one page instead of three.

(c) p. 340. A more irritating example of bad craftsmanship occurs here. The subject under discussion is the use of sodium dichromate as an inhibitor of the corrosion of zinc in water and sodium-chloride solutions. The text merely states : " The dichromate is usually neutralised to the chromate state. The concentrations for most effective use have been studied (Table 8)." We turn to Table 8 and find that this occupies a full page. It consists of a mass of heterogeneous data with a number of qualifying footnotes. No doubt a determined reader could deduce from this Table the desirable concentration of inhibitor, but this would only be after considerable study, which he should not have been called upon to undertake. It would have been far simpler and more effective to write something like this : " The effect of sodium dichromate in inhibiting the corrosion of zinc by water and sodium-chloride solutions has been studied by Roetheli and Cox " (giving the reference). " It may be concluded from their results that the desirable concentration of inhibitor is *so-and-so* " (making such qualifications as may be necessary to allow for the effects of differences in the concentration of the solution).

This raises an important general principle regarding the writing of scientific text books, particularly those bearing on technology. The scientist's function is not only to obtain, adduce, check and correlate observations and experimental data but also to expound them with the maximum lucidity and simplicity at his command. Emphasis should be on essentials, and in all cases where conclusions can be drawn with reasonable certainty, he should draw these conclusions himself, rather than expect the reader who is looking for guidance to make up his own mind about facts of which he may have no direct experience.

(d) Some of the diagrams could have been improved. Consider, for example, Fig. 8 on p. 693. This has an overall area of about 6 sq. in., whereas the data themselves only cover 1 sq. in. The scale could have been enlarged with advantage. Or again, in Fig. 1 on p. 865 two cardinal errors of style occur in the bar diagrams ; some are discontinuous—i.e., cut in the middle, and the scale is varied throughout the length of the bars.

5. Another major weakness is that, owing to the fact that many of the writers are intimately connected with individual, if important, sections of the metallurgical or protective coatings industries. a direct comparison of the merits of different types of metals and alloys is often lacking. Thus the comparative tests on the atmospheric corrosion of non-ferrous metals and alloys conducted by Committee B-3 of the American Society for Testing Materials are in no place considered as a whole. The results obtained after ten years' exposure are to be found scattered over the book in about eight different Tables or text references. The reader who wishes to know, say. whether nickel or aluminium is likely to withstand corrosion better in marine atmospheres will find no direct answer to his question but, once again, have to worry the thing out for himself. The same applies largely to the relative merits of different types of protective coating—e.g., zinc- or cadmium-plate on steel.

As regards the get-up of the book, Messrs. John Wiley & Sons, Inc., have maintained the high standard

of binding and general production that one expects from them. Their printers have grappled efficiently and well with a vast volume of highly complicated tabular matter ; in the course of several hours' study of the book less than half-a-dozen minor printer's errors have been noticed. The half-tone illustrations fall below this high standard. Some of the original photographs themselves are not good, and they have not been improved by printing them on the same paper as the text.

The grave omission of an author index has already been mentioned ; the subject index itself might be better. There are gaps in this—for instance, "Sherardising" will be sought in vain. Some of the cross-references are unnecessary, although we could ill spare one at least which has an almost Handleyan lilt : "Sea-water (*see* Water, sea)." In general, where cross-references are in an index, a check should be made to ascertain whether the same result could not be more simply achieved merely by repeating the page number(s) concerned.

The enumeration of these criticisms has taken some little time, but their importance should not be exaggerated. We must not allow these blemishes, for the most part of a minor character, to blind us to the magnitude and the value of the accomplishment of our American colleagues. There is much that is original and praiseworthy in their work, as, for instance, G. W. Seagren's admirably concise and lucid account of paints and organic coatings for sea-water exposure (pp. 430–433), or the method of presentation adopted by F. L. LaQue in his Tables showing the sea-water corrosion of galvanic couples (pp. 420–426). The main fact is that the authors as a body have surveyed the whole corrosion field and assembled the greater part of existing knowledge, hitherto scattered, under one cover. No doubt many of the minor deficiencies mentioned will be made good when the book is revised ; meanwhile, to quote Dr. Uhlig again : "It is hoped that, in addition to serving as an authoritative reference, this book will stimulate appropriate experimental work directed towards supplying what is now missing."

Let us give credit to the Corrosion Division of the (American) Electrochemical Society for rendering a thorough, conscientious and valuable service to mankind.

J. C. HUDSON.

Electrolytic Polishing and Bright Plating of Metals

By S. Wernick, Ph.D., M.Sc. London, 1948, Alvin Redman, Ltd. xv + 243 pp. Price, 30s. Foreword by Ulick R. Evans, M.A., Sc.D.

ELECTROLYTIC polishing and bright plating of metals are two closely-related processes and may well be studied together. It was, therefore, an excellent idea to treat the two subjects in one volume. They both represent an invaluable contribution by electrochemists to the difficult problem of meeting an increasing and world-wide demand for an attractive finish on metal articles of all kinds, by reducing or entirely obviating the necessity for laborious and costly mechanical-polishing methods. These latter, as Dr. Wernick points out, constitute a real bottle-neck in meeting the great demand for effective surface finishing referred to. There is serious shortage not only of material but also of suitable plant and skilled personnel.

Of the two methods named, bright plating probably came first—i.e., the development of bright-plating solutions or electrolytes depositing a highly lustrous metallic coating which needs no further polishing ; and this was followed by the still more important electrolytic polishing which has evoked universal and rapidly growing interest both from the scientific and practical points of view. This is evidenced by the voluminous bibliography which in recent years has grown up in this field. In the present work there are over 500 references, and the value of this list is greatly enhanced by the addition in many cases of brief critical notes. This novel and very useful feature must have entailed a considerable amount of labour.

The need for a book in English on the subject was indeed urgent and overdue, and although it has in part already appeared as a series of articles in one of the leading metal-finishing journals, the work contains much additional material ; but publication in book form has been delayed owing to difficulties which are well known. The matter has been much condensed, and compared with Jacquet's great work, the first volume of which has been reviewed in these columns (*Metallurgia*, July), the book is small and rather expensive. However, much valuable material has been packed into small compass, and the value of a work cannot be properly judged by size alone. It appears to be the first book in English, and it would be difficult to name anyone better qualified for the task than Dr. Wernick, one of the best-known authorities and consultants, and a Past-President of the Electro-depositors Technical Society. In this latter connection he was largely responsible for the brilliant success of the 3rd International Electrodepositors Conference, the proceedings of which have been lately published, containing *inter alia*, many valuable papers on electrolytic polishing.

The scope of the book covers a brief history of electrolytic polishing development and its application to stainless steels, nickel, aluminium, copper, silver, and carbon steels ; and the bright plating of most of these, as well as zinc and cadmium ; also deposition of platinum, palladium, and rhodium ; with an appendix on bright nickel plating in America.

In the historical section it is stated that Jacquet in France made a careful study of electrolytic polishing from 1935 onwards. It would seem, however, that he began somewhat earlier, in 1929-30 in fact. In a foreword to the first volume of Jacquet's Le Polissage electrolytique des Surfaces Metalliques et ses Applications, Prof. G. Chaudron says that :

In 1930, P. Jacquet, then a young beginner in the industry, had to solve a problem connected with the polishing of nickel wire used as electrodes in emission lamps, without the use of mechanical polishing. . . . At the end of 1931 in preparing a thesis for his doctorate degree, including a micrographic study of the structure of copper, he described a method of anodic dissolution.

Jacquet himself says, in his introduction, that the method of electrolytic polishing of metals and alloys was discovered by H. Figour and P. Jacquet in 1929 in the Labs. de la Soc. Le Materiel Telephonique. It appears, however, that there was a certain amount of work about the same time in this country—e.g., by N. R. Laban (in a paper read before the Electrodep. Tech. Soc. in 1930) ; and even earlier in the U.S.A. by C. P. Madsden in 1925, and in patents (U.S.) by Burns & Warner.

From the metallurgical and scientific point of view probably the most valuable aspect of electrolytic polishing is in micrographic examinations, for which brightly-polished surfaces can be prepared most effectively by electrolytic methods, without change in structure or setting up of strain or other serious inconveniences inseparable from mechanical polishing. This is not included in the present volume which is essentially of a practical nature and intended presumably mainly for the student and worker in plating and similar establishments. For these it is an excellent and compact little textbook, even if for such readers the price, as already intimated, is high.

W. G. CASS.

New Melting Shop at the Appleby-Frodingham Steel Works

The post-war reconstruction programme of the iron and steel industry is steadily being transformed into new and improved plant. Some idea of the developments being undertaken is given by this description of the new melting shop of the Appleby-Frodingham Steel Company.

THE first of the new melting shops to be constructed to modernise the British Steel Industry, and also to meet the very heavy post-war demand for steel, was built on a site to the south of the existing plant at the Scunthorpe works of the United Steel Companies.

This plant, commencing operation in the latter part of 1947, incorporates one 600-ton active metal mixer, two 300-ton tilting furnaces, two 140-ton ladle cranes, and two 4-ton ground type furnace chargers, constructed by The Wellman Smith Owen Engineering Corporation, Ltd., London, who also designed this equipment with the exception of the tilting furnaces, which were designed by The Appleby-Frodingham Steel Company in close collaboration with Wellman engineers.

The furnaces are charged with 75% hot metal and 25% scrap and are capable of producing an average of 2,300 tons of steel per week. They are fired with mixed gas, but provision is also being made to give luminosity to the flame by the addition of heavy liquid fuel or creosote pitch.

General view of shop showing two 300/350-ton tilting furnaces, one of the two 140-ton ladle cranes and in the background the 600-ton hot-metal mixer.

Furnace Body

The hearth is approximately 650 sq. ft. at sill level, being 45 ft. long and 15 ft. wide, and the maximum depth of the bath from sill level is 3 ft. 6 in. Front and back walls are sloped at an angle of $12\frac{1}{2}°$. The length of the furnace over the chills is 54 ft. 4 in.

The sides and bottom of the body are fully plated, stiffened on charging and tapping sides, with large heavy steel channels rigidly connected by transverse-plate girders. These girders are also stiffened with horizontal diagonal bracing, which ensures longitudinal rigidity. The bottom and sides are fixed to joists which are supported on three box-type roller girders having a 2-in. boom plate of 0·45 carbon steel which forms a roller path running on a pair of cast-steel rollers. Compensating rocker brackets carry the cast-steel rollers and are equipped with pins of 3% nickel steel machine-fitted in lubricated gunmetal-lined bearings. Each pair of compensating rocker brackets is supported on suitably braced-girder type bed plates.

The ends of the body are of ventilated-box formation, to the outer face of which is attached a conical-shaped steel casting with flanges to fix to the body structure and to take a cast-steel water-cooled chill. A continuous thick steel band on the face of the chill ensures surface contact over the full range of slagging and tapping angles. Platforms are fixed on both sides of the furnace at stage level to maintain a minimum tilting clearance between the furnace and the charging stage.

Doors

There are five doors on the charging side, three being 3 ft. 10 in. wide and the remaining two 4 ft. 10 in. wide. The archplates are of welded construction, water-cooled to ensure circulation over the surface of the frame, and the jambs are of hollow-box construction. The two wide doors have slag notches in the foreplate and are also fitted with removable splash plates to protect the door frame. All the doors are of welded construction and are water-cooled. They are lined with $4\frac{1}{2}$-in. fireback, which

Close up of 600-ton active metal mixer.

type constructed with 3-in. bricks. The side walls and the roof of the regenerators are insulated and the ends are plated and suitably stiffened with vertical channels and joists which are rigidly held in position by horizontal compound girders.

Flues and Dampers

The flues are streamlined to reduce pressure loss to a minimum and the gas flues from the inlet valves to the regenerators are encased in mild-steel plates to ensure that there is no possibility of gas leakage. The gas-reversing valves are of the mushroom type, 3 ft. 5 in. dia., with a cast-steel valve in a cast-iron water pan giving a $3\frac{1}{2}$-in. water seal. They are mounted on a mild-steel casing which is fitted with an explosion door on a large removable plate which permits the withdrawal of the mushroom valve. The gas-reversing dampers have extra wide water-cooled seats, the hematite iron dampers being reinforced with mild-steel plates. The air-reversing valves are of the straight-through double-deck type. The lower seat is water-cooled and the dry dampers are machined to ensure even contact with the seat. The valve is fitted with a mild-steel cover plate and has a natural draught air-inlet valve.

The air fan, which is capable of delivering 12,500 cu. ft./min. at a pressure of $3\frac{1}{2}$-in. W.G., has a multivane-type impellor overhung on a rigid steel shaft which is connected to the variable-speed motor shaft by means of a Bibby flexible coupling. The fan is connected to the air-reversing valve by mild-steel tubing in which is installed an orifice plate and the butterfly-type valve.

There are three electrically-operated valve-reversing units, one of which operates the air-reversing valve, and the other two operate the gas-reversing dampers and corresponding gas-reversing valve. Each unit consists of a 5-h.p. geared motor unit which has a winding drum fitted with split sheaves which automatically prevents overwinding on reversal.

The main chimney damper has a water-cooled seat on which slides a dry reinforced iron damper which is fully balanced and is operated by a 2-h.p. motor directly coupled to a reduction gear box with a rope drum on the output shaft. This damper can be operated from the stage, and so that it can be held in any required position to suit the necessary draught, a solenoid brake is fitted to the motor coupling. There are also two vertical floating-type dampers which are automatically controlled ; one of these is in the main chimney flue and the other in the chimney flue from the air regenerators.

Tilting Gear

The furnace can be tilted through an angle of 35° for tapping and an angle of 15° for slagging, by means of electric-tilting gear, which consists of two rams attached to the rockers of the furnace and carrying heavy racks operated by worm-and-spur gear-reduction units which are coupled to a 60-h.p. motor by means of a Wellman Bibby flexible coupling. There are two tilting units coupled by a cross shaft, each unit being capable of tilting the furnace. The gear has an automatic Igranic electric brake, fitted with a Ferodo lining, which ensures that

at intervals is bonded over the full depth of the door. Mild-steel brackets are attached to prevent the doors from swinging away from the frame when the furnace is tilted. Each door is operated by a 2 h.p. geared motor unit, having an extended shaft on which is mounted a winding drum. To prevent overwinding without the use of limit switches, split sheaves are fitted to the drum. The doors are fully balanced, and to ensure that the doors will remain open in any position to suit charging or sampling operations, each hoist unit is fitted with an electro-mechanical brake. Push buttons for controlling the hoisting gears are mounted on the control desk on the stage facing the furnace.

Port Ends

The port ends are of the Friedrich type, the front removable block being approximately 5 ft. long. In this is built a single air port, 2 ft. 6 in. deep by 9 ft. 2 in. wide, superimposed on a single gas port, 2 ft. 4 in. deep by 2 ft. 9 in. wide, around which are arranged water-cooled pipes which can be individually controlled. The block is of rigid structure with lifting lugs, and when in position is supported on girders forming part of the main stage. On the front of the block are bolted cast-steel water-cooled chills, in sections, around which is a thick continuous steel band which closes the gap between the port end and the furnace, and also allows for the necessary expansion of the furnace body. The rear end of each block is built solidly to the fixed port end with a 9-in. silica joint, which can easily be broken from both sides of the furnace when the block has to be replaced.

The fixed port end is plated and forms a rigid structure which is supported by stage girders. The two air uptakes are 3 ft. 1 in. × 4 ft. 3 in., and the gas uptake, the back wall of which is water-cooled, is 3 ft. 6 in. × 5 ft.

Slag Pockets and Regenerators

The air-slag pocket is 16 ft. 6 in. × 11 ft. 5 in. × 8 ft. 1 in., and the gas-slag pocket 16 ft. 6 in. × 7 ft. 1 in. × 10 ft. 3 in. Air checkers are 19 ft. 6 in. × 17 ft. $1\frac{1}{2}$ in. × 12 ft. 10 in. and gas checkers 19 ft. 6 in. × 19 ft. $3\frac{1}{2}$ in. × 8 ft. 6 in. ; these are of the straight through

the brake automatically comes into operation on failure of the current. Ample provision is made for lubricating the racks and gears which are all enclosed in heavy housings.

Chargers

Two Wellman charging machines of the revolving-floor type, having a capacity of 4 tons each, are employed for charging scrap metal and other additions into the furnaces. The machines run on heavy rails placed at 26-ft. centres and have a height measured from rail level to centre line of charging bar of 4 ft. The forged-steel charging bars made in two sections have a length from the centre line of the machine of 21 ft. 3 in. and handle charging boxes 7 ft. long. Shop travel is performed at a speed of 400 ft. per minute, two gears each equipped with 40-h.p. motors driving on to all four track wheels being provided for this purpose. The machines have a cross-traverse movement of 19 ft. 6 in., an all-round turning movement enabling a swing round from back to front to be made in 7½ seconds, a crank-operated hoist, and a bar-turning motion. Wellman-Bibby flexible couplings and Igranic brakes are fitted to all motions.

Two Wellman ladle cranes of 140 tons lifting capacity serve the casting shop and operate on a 220 volts direct current supply. They are placed on a track 56 ft. above ground level and run on rails giving a span of 60 ft. The cranes have a long travel speed of 150 ft. per minute, main trolley cross travel of 70 ft. per minute, and hoist of 7 ft. per minute. Each crane carries an auxiliary trolley of 25 tons lifting capacity running on its own twin girders situated within the main girders. The auxiliary trolleys have a lifting speed of 25 ft. per minute and a cross traverse of 100 ft. per minute.

The driver's cab is dropped to a height above ground level of 25 ft. 3½ in., thus providing a good view of operations. The cab carries the control gear only, leaving the contactor panels, the resistances and other electrical gear to be accommodated in the compartments provided above. Wellman-Bibby flexible couplings are fitted to all drives. Load lowering of both main and auxiliary-hoist loads is electrically controlled by dynamic braking under potentiometer control. Igranic brakes for load holding are fitted to both hoists.

The ladle cranes serve not only for the handling of the furnace casts but also for pouring the incoming ladles of hot metal into the 600-ton Wellman mixer.

Recent Developments in Materials, Tools, and Equipment

Flamemaster Hand Torch

THE Flamemaster hand torch has been designed to cater for all trades using small and medium-sized flame processes, and it is believed that it will provide the answer to many production problems in the glassworking, electrical and general engineering industries as well as in the jewellers' and associated trades. The Flamemaster torch has quick-action needle valves with conveniently placed thumb control for the gas and air or oxygen supplies. A built-in, leakproof, economiser cuts off the gas and air supplies when the operator's grip is relaxed and restores the flame when the torch is gripped. The same control enables a soft, warming-up flame to be obtained by partial operation of the lever. The pilot flame is adjustable to suit various gas pressures. Seven interchangeable flame units are available, providing flames of 2–10 in. in length and various thicknesses, suitable for all kinds of work and temperatures ranging from moderate to very high.

The Flamemaster hand torch

Among the advantages offered by the Flamemaster are the following : (1) Flexibility ; (2) economiser cuts gas consumption by at least 30% ; (3) the Flexiflame jet unit gives a wide range of flame sizes merely by adjustment of gas supply by thumb-operated, quick-action needle valve ; (4) two sets of three alternative flame units are available for special duties with gas/air and gas/oxygen ; (5) complete with built-in economiser the Flamemaster weighs only 13 oz.

In order that the improved handling qualities of the torch shall not be impaired by clumsy rubber hose, a special twin-bore tubing, which will not kink or develop awkward loops, has been developed.

A double tipping or sealing attachment can be provided which screws on to the torch in place of the removable nozzle and is useful for glass ampoule sealing, etc. For light soldering work, a soldering bolt attachment is available which converts the torch into a very convenient gas-heated soldering iron with precise heat control.

Messrs. Chance Bros., Engineering Division, Lighthouse Works, Smethwick, 40, Nr. Birmingham.

Small compressors capable of serving several Flamemasters are obtainable from Messrs. W. Edwards & Co., who can also supply the torches and accessories.

Messrs. W. Edwards & Co. (London), Ltd., Kangley Bridge Road, Lower Sydenham, London, S.E.26.

Metrovick 85 kVA Bar-heating Machine

THE Metropolitan-Vickers Electrical Co. have designed a machine for the electrical-resistance heating of bars prior to their being bent, formed or forged. This method of heating is replacing the older furnace methods chiefly because of the advantages of :—(1) Its cleanliness compared with furnace methods. (2) Higher speed of heating. (3) Reduced scaling because of the shorter time the bar is held at high temperature. (4) Uniform heating. (5) Economy in man-power and fuel because—

Bar-heating machine

end is ground the piece is finally ejected by cam action down the chute E. The feeding chute is fitted with suitable checks to prevent the operator from inserting the pieces wrongly, and it is also provided with an end gate which lifts to permit the passage of a single piece at a time to the rotating carrier. The rotation of the latter is clockwise, and at very slow speed. Immediately before the piece makes contact with the grinding wheel, axial rotation is imparted to it by the control wheel C, which is urged towards the work by spring pressure.

In the case of example C, Fig. 1, the requisite profile is produced on the grinding wheel by a standard form-truing attachment at the rear of the wheel controlled by a former ; but for other profiles there are available for dressing the wheel such alternative devices as radius-truing attachments, overhead crush-forming attachments, or combinations of these methods.

(*a*) it is energised and attended to only when in operation,
(*b*) it has a smaller area for radiation than a furnace.

The machine is of extremely robust construction, designed for heating mild-steel bars from $1\frac{1}{2}$–$2\frac{3}{4}$ in. dia. to temperatures in the region of 1,000° C. over a length of from 13 in. minimum to 20 in. maximum. One of the bar-clamping electrodes is adjustable for the different bar lengths, the adjustment being controlled by a hand wheel at one end of the machine. Bars are clamped in the horizontal position and can be loaded either from the front or from the ends of the machine.

A pre-set control-type radiation pyrometer holds the temperature within ± 30° C. of the set figure. A $2\frac{3}{4}$-in. dia. bar can be heated to 1,000° C. over a length of 20 in. in $1\frac{3}{4}$ minutes ; a $1\frac{1}{2}$-in. dia. bar over a length of 13 in. takes only 20 seconds.

Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17.

End-forming Machine
Novel variation of centreless principle

THERE are certain components which require a profile grinding, on the end, of such form that it could not be dealt with on any normal centreless grinding machine on account of wheel wear and breakdown or the difficulty of truing such a profile from any normal truing attachment. Amongst such pieces might be mentioned the bearing end of gramophone spindles, bicycle bottom bracket axle ends, textile carding pins, and certain types of gramophone and other needles, or in fact, any component with an end profile between A and B, Fig. 1. For this purpose an entirely new type of end-forming machine has been developed, of which a number have been supplied to the British bicycle industry.

In certain features the new machine is a variation of the conventional centreless grinder, and the principle of operation will be readily followed by reference to the diagram in Fig. 2. A is the grinding wheel which is dressed to the required profile by suitable means ; B is a rotating work carrier which presents the pieces at right angles to the face of the grinding wheel ; while C is a smaller abrasive control wheel which imparts the requisite rotary movement to the piece during the time it is in contact with the grinding wheel. The operation is entirely automatic, the pieces being fed to the rotating work carrier down the inclined chute D, and when the

| Fig. 1. | Fig. 2. |
| Examples of end profiles required. | Diagram illustrating principle of new machine. |

The design of the rotary cage or work carrier naturally depends upon the component to be ground, and in the example illustrated consists of a large circular drum carrying a series of rollers mounted on the face, in such a position that one workpiece is supported between each pair of rollers with its axis radial to the drum.

A number of these machines have been installed in a large bicycle plant in this country for grinding the ends of bottom-bracket axles, which require a high degree of finish for subsequent plating, this question of end-finish being a point to which great importance is attached in the industry, quite apart from the close degree of accuracy required on the bearing surfaces of the component. The hourly production of each machine on this particular component is 1,800 ends, and compared with the older method of hand grinding or polishing the economies which can be realised by the new machine on certain classes of component are sufficiently considerable to enable the initial cost to be recouped in less than a year and a half's working.

Arthur Scrivener, Ltd., Tyburn Road, Birmingham.

Light Metals Bulletin

IT is announced, by the British Aluminium Co., Ltd., that, as from the beginning of 1949, *Light Metals Review* and its companion journal, *Light Metals Research*, are being combined into a single abstract journal, *Light Metals Bulletin*, to be published fortnightly.

IT is precisely a year since we referred, in these columns, to the recently instituted Fisher Award in Analytical Chemistry which had been announced in the United States of America. A further step in the recognition of the place of analytical chemistry is formed by the Merck Fellowship in Analytical Chemistry. This is a graduate fellowship of the value of $2,500 per year, and will be offered for at least three years. The fellow is to be that person most likely to contribute most to the advancement of the theory and practice of analytical chemistry, not merely during the tenure of the fellowship, but also during the course of his future career. Thus the Fisher Award recognises past contributions to the subject, while the Merck Fellowship is given with the complementary object of encouraging the future. It may be reasoned that industry in the United States shows, and very concretely, not only that it recognises the contributions made in the past by analytical chemists to the advancement of chemistry in general, but that it also refuses to regard this branch of the science as even at its peak. We do the donors of the Merck Fellowship the justice of believing that they are not offering this money in respect of the dotting of i's and the crossing of t's. They obviously expect that the coming years are capable, under the right guidance, of producing fundamental advances equal to any which we have seen in the past fifty years—or, taking the comprehensive view, in the past hundred and fifty years. Analytical chemists everywhere will undoubtedly appreciate this attitude of trust for their continued progress.

Extending the Range of the Spekker Absorptiometer, with particular reference to the Determination of Silicon in Aluminium Alloys

By William Stross, F.R.I.C.

The useful measuring range of the Spekker photo-electric absorptiometer is limited to extinctions not exceeding the value of 1·3, whilst for certain purposes it is useful to extend the range. A technique is described by which this range can be doubled. After setting the instrument, a filter of suitable absorption is inserted asymmetrically, on the left-hand side only, and a galvanometer four times more sensitive than the one usually supplied with the Spekker is used. The application of this technique to the determination of silicon is discussed in detail.

THE logarithmic scale on the measuring drum of the Spekker photoelectric absorptiometer[1] extends to about 3·0, but beyond 1·0 on the older (1·3 on the more recent) instruments the calibration is too coarse for a reasonably accurate measurement (on setting) it is, therefore, not recommended by the makers of the instrument to use the instrument beyond this range, except for semi-quantitative purposes.

Two different techniques of taking measurements on the Spekker have been described :

(a) The technique advocated by the makers of the instrument. The measuring drum is set at zero (i.e., the aperture is set at its maximum opening), the coloured solution under test is brought in the light beam and the cells are balanced by adjusting the iris diaphragm on the left-hand side ; the coloured solution is then replaced by the solvent and the cells balanced again, this time, however, by *closing* the measuring drum, thus directly obtaining the extinction.

(b) The alternative technique recommended by Vaughan[2] (i.e., the so-called " setting water-to-water."

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1 For full details see F. W. Haywood and A. A. R. Wood, Metallurgical Analysis by means of the Spekker Photo-electric Absorptiometer. A. Hilger, Ltd., 98, St. Pancras Way, London, N.W.1, 1944 ; see also the instructions supplied by the makers of the instrument, Messrs. A. Hilger.

2 The Use of the Spekker etc., Institute of Chemistry, London, 1941.

The instrument is first " set " by balancing the photo-cells with water (solvent) in the cells on either side and with the measuring drum *strongly* closed down to a predetermined suitable value ; the water (solvent) on the right-hand side is then replaced by the coloured solution under test, and the increased light absorption on this side is compensated by *opening* the measuring aperture until the galvanometer shows zero again. The " drum reading " thus obtained can either be used as such for plotting graphs (or for evaluating the measurements from existing graphs) ; or the drum reading can be transformed into extinction by subtracting the drum reading from the setting or from the " blank " drum reading.

The modification of this technique recommended by J. H. High[3] (i.e., setting with only *moderately* closed measuring drum, not against water, but against a neutral-grey Chance's filter inserted on the right-hand side of the instrument, which filter is then removed after the setting) can, for the purpose of this discussion, practically be identified with Vaughan's technique.

The technique (*a*) will not be considered any further in the following, as it is too tedious to be used in practice if a large number of measurements has to be made.

It is obvious that the technique (*b*) sharply limits the measuring range, but this is hardly a practical disadvantage in view of the poor definition of drum readings beyond 1·0 or 1·3, respectively.

It is in principle quite easy to adapt the analytical conditions to these limits by an adequate choice of the weight of the sample (or of the final volume of the solution, or of the depth of the cell) and of the kind of filter used. If, however, a calibration graph covers a wide range, the slope of the graph versus the axis representing the percentage will obviously be comparatively shallow ; this increases the significance of the measuring error or, in other words, the extension of the range may decrease the accuracy of the method to an undesirable extent. If, on the other hand, the accuracy is to be kept high by restricting the measuring range this may frequently in practice lead to solutions being " immeasurable "—i.e., too dark to be measured under a certain set of conditions. This will frequently happen if the objects under test vary widely in their composition and if little is known in advance about the composition of each specimen.

Using filters of various selectivity (or cells of varying depth) also requires an increased number of calibration graphs and the frequent changing may become a nuisance and a potential source of errors, particularly in large-scale routine work.

Diluting a solution after an unsuccessful attempt at measuring is not permissible in many cases, apart from the practical inconvenience. It will usually be more convenient to abandon " immeasurable " samples and to start a fresh test on a smaller sample.

In our routine work on aluminium alloys this type of inconvenience made itself felt particularly in the determination of silicon, for which purpose we are using the method based on the yellow colour of the silico-molybdic complex. The alternative method, based on reducing this complex to the molybdenum blue is probably in practice less subject to this type of inconvenience as a master solution is prepared in each case of which a different aliquot can be taken comparatively quickly if

3 *The Analyst*, **66**, 1943, 78.

the first test was done on an unsuitable volume. It is, however, thought that this advantage is outweighed by the greater complexity of the method, as far at least as the routine analysis of the usual commercial aluminium alloys is concerned.

The silicon content of the commercial aluminium alloys ranges from about 0·25–14% and more, and it has been recommended[4], [5], [6] to cover this range by three different procedures, which can be shortly summarised as follows :

1. Alloys with less than approximately 1·5% Si ; a 100 mg. sample is made up to a final volume of 100–110 ml.

2. Alloys with 1·5–3% Si ; a 100 mg. sample is made up to a final volume of 200–220 ml.

3. Alloys with 3–14% ;* a master solution is first prepared from a 100 mg. sample and an aliquot of this is diluted to give a final concentration of 10 mg. per 100–110 ml.

It is obvious that procedure (3), requiring more manipulation and apparatus, takes more time than the other two procedures.

The calibration graphs obtained under these conditions, using a mercury lamp, a 4-cm. cell and 601 (violet) Ilford Spectrum filters, protected by heat-absorbing filters, are illustrated by curves 1, 2, and 3 of Fig. 1.

It will be found that the range 6–9% Si is hardly represented among the commercially important alloys and has, therefore, a comparatively small practical importance.

The important range 3–6% is, however, covered by a part of the graph which is unfavourable with respect to the percentual accuracy obtainable.

It has, therefore, been our practice for some time to extend the range of procedure (2) by applying it to 50 mg. samples, using 1 ml. less of the 7·5N acid than is being used for a 100-mg. weighing.[6] The calibration graph thus obtained is represented by curve 4 of Fig. 1 ; it will be seen that a much more favourable slope is thus obtained than that of curve 3, although it is less favourable than that of curve 2. It seemed, therefore, desirable to improve it still further.

For the analysis of steel for silicon by the molybdenum-blue method the measuring range has been extended by J. Little[7] by setting the Spekker at 2·0 " water-to-water." To cover the desired range under our conditions necessitated an even higher setting than 2·0. It was found then that the accuracy of the setting and of the drum readings obtained was poor as the response of the galvanometer to the movement of the measuring drum was too sluggish—in other words the photo-electric current emitted by the cells was too weak.

Apart from this a setting at a value considerably higher than 1·3 entails another disadvantage : such a setting—say at 2·6—obviously renders useless a measurement falling between this setting and 1·3, as it will not come within the suitably calibrated part of the measuring drum. For such a solution the instrument would have to be reset at, say, 1·3, with the corresponding loss in time.

An extension of the useful range of the Spekker, though on a smaller scale, was previously suggested by

* Alloys with still higher contents are not considered here as they have not been found very suitable for the photometric technique, probably because of the difficulty of obtaining a representative sample.

4 Hadley, W. H., *Analyst*, **66**, 1941, 486 ; **67**, 1942, 5.

5 Chemical Analysis of Aluminium and its Alloys. The British Aluminium Co., Ltd., Publication No. 405, 1947, 128.

6 Stross, W., *Analyst*, **69**, 1944, 44.

7 *J. Soc. Chem. Ind.*, 1945, 118.

the writer, to compensate for a high "blank" in the determination of magnesium[8] and of beryllium[9]—two methods in which the *reagent* used has a strong light absorption. A Chance No. 5 (green) filter, having an extinction value of about 0·5 in combination with the Ilford 604 Spectrum filter, was recommended for this purpose; the Spekker is set "water-to-water" at 1·30, with the heat absorbing and Ilford 604 filters symmetrically inserted on either side and *after this*, without altering the setting, one Chance No. 5 filter is

Chance neutral-grey filters were suitable—i.e., those with an extinction value not greater than 1·30.

Among a number of neutral-grey filters examined by the writer, the majority had an extinction value of 1·45 or more, and this makes them unsuitable for this application as, with a setting of 1·30, the asymmetrical insertion of such a filter would produce a gap between the end of the first and the beginning of the second measuring range (see below), whilst the two ranges should overlap slightly.
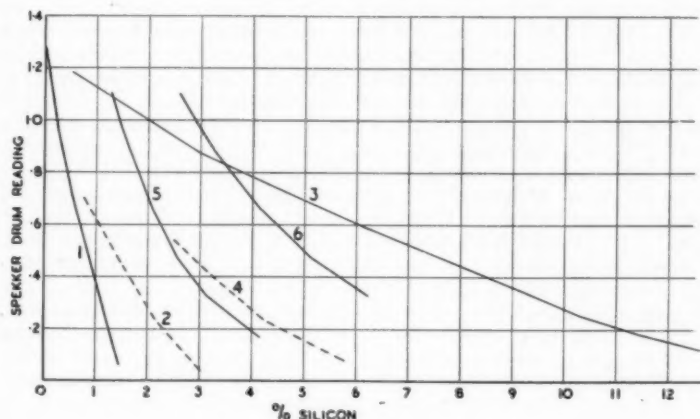
Fig. 1.—Calibration graphs for the different ranges of silicon content. A 4 cm. cell, the mercury-vapour lamp, "Calorex" heat absorbing and Ilford 601 Spectrum filters were used throughout.

Curve 1.—Sample: 100 mg.; final volume: 100 ml. ("low" range).

Curve 2.—Sample: 100 mg.; final volume: 220 ml. ("medium" range).

Curve 3.—Sample: 10 mg.*; final volume: 110 ml. ("high" range).

Curve 4.—Sample: 50 mg.; final volume: 220 ml. ("extended medium" range).

All these curves were obtained without using an asymmetrical filter.

Curve 5.—Sample and processing technique as for curve 1; for the purpose of measuring an asymmetrical filter was inserted.

Curve 6.—Sample: 50 mg.; final volume: 110 ml., also measured with the use of an asymmetrical filter.

To appreciate the relative merit of the curves 5 and 2 (covering a similar range) only the part between 1.5 and 3% Si should be compared with regard to the slope; the most important point regarding the general usefulness of the technique is, however, the fact that the entire range from 0–4% is now covered by one and the same sample, whilst previously up to three different samples had to be processed by three different techniques, according to whether the silicon content of the sample fell into the expected range or not.

The curves 1, 2, and 3 represent the old technique, 1, 5, 6 and 3 represent the modified technique, the procedure for obtaining curves 1 and 5 differing only with regard to the technique of measuring.

inserted, asymmetrically, on the left-hand side only; this compensates for most of the blank, so that practically the full range of the Spekker is available for the measurement of the colour change produced by the element under test.

When the filters available to the writer were tested for the range of extension which they provide when inserted asymmetrically in combination with the Ilford 601 Spectrum filters, it was found that some specimens of
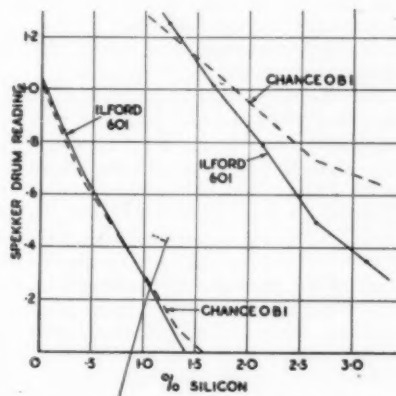
Fig. 2.—Comparison of Chance O.B.I. and Ilford 601 Spectrum filters. In the range 0–1·5% (i.e., without the insertion of an asymmetrical filter) the performance of both filters is nearly identical. In the higher range, however, which has been made measurable in both cases by the asymmetrical insertion of one Chance neutral-grey filter, the difference in favour of the Ilford filters becomes very marked. The other optical conditions were as in Fig. 1. The curve was drawn exactly through the points determined in this particular experiment, hence, the slightly irregular shape of one of them.

If no suitable neutral-grey filter is available, a pair of Chance O.B.I. filters—each of which singly has an extinction value of about 0·5 in combination with the Ilford 601 filters—can be used for the same purpose. In this case it is advisable to use High's technique,[3] for the setting—i.e., to set against the two O.B.I. filters placed on the *right*-hand side, whilst the measuring drum is kept fairly widely open. The opening of the measuring drum should be so adjusted as to add up with the extinction value of the two O.B.I. filters to something like 1·4 or 1·45. As the commercial caustic soda contains, even if of A.R. grade, sufficient silica to produce a "blank," having an extinction value of at least 0·15 under the working conditions used,[6] the drum reading representing 0% silicon content *of the alloy* will still fall within the accurately calibrated part of the measuring drum, and the two parts of the graph will overlap conveniently.

In using either of these techniques the sluggishness of the galvanometer response as mentioned before was again observed. The use of a more sensitive galvanometer was the obvious answer.*

8 Stross, W., *Analyst*, **67**, 1942, 317.
9 Stross, W., and Osborn, G. H., *J. Soc. Chem. Ind.*, **63**, 1944, 249.
* This concentration is obtained by taking an aliquot of the master solution prepared from the original weighing of 100 mg.

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* A stronger light source could be expected to serve the same purpose. Only one type of mercury-vapour lamps fitting the Spekker seems, however, to be obtainable commercially, and the mercury lamp is desirable for the silicon determination. For cases where a filament lamp is equally suitable a 200 watt lamp of suitable dimensions is available (the ordinary lamp is of 100 watt), but a very few orientating experiments with such determinations make it appear doubtful whether the use of an increased amount of light really comes up to expectation.

Messrs. Tinsley (Industrial Instruments), Ltd.* supplied an instrument of the type VS4/45, but fitted with a shunt so arranged that its sensitivity could rapidly be increased from a sensitivity similar to that of the Cambridge spot galvanometer** to a sensitivity four times greater. Using this galvanometer, the following procedure proved satisfactory :

Alloys with up to 3% silicon are treated according to procedure (1),***—i.e., 100 mg. of alloy are made up to a final volume of 110 ml. (including the molybdate).

Fifty mg. samples are taken of alloys with 3–7% silicon ; they are processed in the same way—except that the quantity of acid used is reduced by 1 ml.—and made up to the same final volume.

Samples with 7–14% silicon are treated according to technique (3), above.

The Spekker is set " water-to-water " as previously described—i.e., with 601 Spectrum filters and Chance heat-absorbing filters on both sides. A 4-cm. cell and the Tinsley galvanometer at one-quarter of its full sensitivity is used, whilst the sensitivity control of the Spekker is set at full sensitivity.

If the solution is " immeasurable," either one Chance neutral-grey filter or two Chance O.B.I. filters are inserted asymmetrically, *on the left-hand side only.* The heat absorbing plus Ilford filter can usually be accommodated in one of the two slots provided, so that the second slot is available for the neutral-grey filter ; if the heat absorbing plus Ilford filter are too thick to enter into the one slot together, or if two asymmetrical filters are to be inserted, they can be placed beside the water containing protective cell on the left-hand side.

With asymmetrical filters the galvanometer is switched to its full sensitivity. The measurement is carried out in the usual way ; a little more care is perhaps required than for the measurements without asymmetrical filters when bringing the galvo back to zero. It is particularly important o protect the instrument against variations of the stray light that can fall on the photocells from outside. It is, for instance, advisable to hold the hand operating the measuring drum in the same position during the setting of the instrument as during the measurement, so as to standardise the shade it may throw on the cell with the liquid.

It is obvious that the use of an asymmetrical filter, or filters, in the way described, amounts to the same thing as setting the instrument to 1·30 plus the extinction value of the asymmetrical filter—e.g., 2·60, if the asymmetrical filter has an extinction value of 1·3. This procedure has two advantages : (a) The setting is much more accurate than it could be if the corresponding value of the measuring drum were used without a symmetrical filter ; (b) solutions of extinction values below and above 1·3 can equally well be measured in rapid succession without having to alter the setting, mere'y by inserting the asymmetrical filter or by taking it out again. This is particularly useful in " borderline " cases, when it cannot be estimated visually with any degree of

certainty into which of the two ranges a given specimen belongs.

In large-scale outine application it becomes, of course, a very necessary practical precaution carefully to note whether the asymmetrical filter has been used or not, but this soon becomes quite automatic.

A few words may still be said about the various filters recommended for the determination of silicon by the yellow molybdic complex, using the Spekker.[6], [10] The main alternatives are the Ilford 601 and the Chance O.B.I. filters. The Ilford gelatine filters are much more liable to deterioration by heat—particularly if the mercury lamp is used—than the all-glass Chance filters; on the other hand, the transmission data published, make it clear that the Ilford filters transmit a much narrower band from incident polychromatic light. With the mercury-vapour lamp the practical effect of this difference becomes smaller as the discontinuous nature of the vapour spectrum makes up for the lesser degree of selectivity. For the determination of silicon by the above method there is hardly any difference in the calibration graphs obtained with the two types of filters up to an extinction value of about 0·8, as illustrated by the curves 1 and 2 of Fig. 2.

For solutions of higher extinctions, however—e.g., for measurements made with the use of an asymmetrical filter, neutral-grey curve obtained with the O.B.I. filters is far inferior, so that only the Ilford filters can be recommended for this range. This is illustrated by the curves 3 and 4 in Fig. 2.

It will be seen from Fig. 1 and 2 that the calibration curve obtained with the yellow silico-molybdic complex differs appreciably from a straight line, and that this deviation increases considerably with increasing concentration ; this is in contrast to the straight-line calibration graphs published by Little[7] for the *blue* complex up to extinction values of a similar magnitude. The curved shape of the calibration graph is no doubt a practical disadvantage of the recommended procedure, but it is thought, after extensive practical experience, that the advantages by far outweigh the disadvantages.

These experiments were carried out in the laboratories of Messrs. International Alloys, Ltd., in Aylesbury, and the author wishes to thank the directors for permission to publish.

Pacific Science Congress.

THE ROYAL SOCIETY has appointed a delegation of six of its Fellows to attend the Seventh Pacific Science Congress to be held in New Zealand in February of this year. The programme of the Congress will provide for contributions and discussions on scientific topics of special significance to the Pacific area, and of importance for the welfare of Pacific peoples.

The members of the delegation are :—Dr. G. E. R. Deacon, Sir Norman Haworth, Professor H. D. Kay, Professor G. W. Robinson, Sir Geoffrey Taylor and Professor C. M. Yonge.

At the invitation of the Vice-Chancellor of the Australian National University, Canberra, Sir Norman Haworth and Sir Geoffrey Taylor will spend some time in Australia visiting university laboratories before returning to this country.

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* North Circular Road, West Twyford, N.W.10.

** On the Cambridge spot galvanometer normally supplied with the Spekker 90–130 small divisions represent 1 microamp.

*** The following is a brief survey of the procedure : The samples are attacked with 10 ml. of 40% NaOH (40 g. of the solid are dissolved in 100 ml. water) in stainless-steel beakers covered with nickel lids. When the attack is complete the beakers are washed down and *gently* boiled for 5 min., 15 ml. of water and 25 ml. of 5N nitric acid added with vigorous shaking, the solution filtered into 100 ml. wide-necked measuring flasks, cooled to 20–22° C., made up to the 100 ml. mark and 10 ml. 10% ammonium molybdate solution (freshly filtered through double 42 Whatman filters) added. After mixing and 5–10 min. standing the absorption is measured. For details, see (6).

10 Hadley, W. H., *Analyst* 1945, p. 45.

Sheet Metals for High Temperature Service
By P. A. Haythorne

THE rapid development of the aircraft gas turbine and various other sources of jet power have imposed increasingly severe requirements on materials used in their fabrication, and as a result innumerable metallurgical difficulties have arisen, the majority of which have related directly to the metallic components exposed to elevated temperatures in service. Understandably, the major portion of recent metallurgical research, productive of the so-called super-alloys has been devoted primarily toward the improvement of the more critical moving parts of the turbine (turbine discs and blading) with somewhat less emphasis placed on the development and application of sheet materials for exhaust stacks, tail cones, combustion chambers, etc.

However, the sheet metal construction which comprises the bulk of combustion systems has constituted a serious metallurgical problem, and in the case of flame tubes has become a limiting factor in the service life of current jet engines. This has applied to engines of German and British design as well as those manufactured in the United States. It is observed that the repeated alteration of alloy specifications and/or profligate use of strategic alloys has resulted in no substantial reduction in distortion of combustion tube liners or improvement in service life of these and similar components. This may serve as an indication that requirements of sheet metals for high-temperature service may differ considerably from those of such parts as rotors and blading.

Factors of inherently poor thermal conductivity and high-thermal expansion are quite characteristic of the most promising of available high-temperature alloys, and therefore thin sheet sections which are particularly susceptible to the deleterious effects of localised heating and flame impingement, resulting in warpage, distortion and failure from thermal stress gradi-

ents, have proven a most prolific source of trouble in turbo-engines.

A review and analysis of failures previously occurring in sheet metal parts operating at elevated temperatures—exhaust stacks, collector rings and the familiar exhaust manifolds for reciprocating engines—has indicated a marked similarity of attendant metallurgical difficulties to those more recently associated with jet propulsion. Formerly, problems of distortion, thermal fatigue, etc., were solved with moderate satisfaction by such expedients as the increase of sheet thickness or modification of design in critical areas to effectively reduce thermal-stress gradients. However, where these methods were not practicable, or tolerable from a standpoint of excessive weight steps have been taken to reduce the severity of localised heating by the use of composite materials of higher thermal conductivity. The application of aluminium fins to engine cylinder barrels and the copper cladding of stainless-steel cooking utensils are examples of this approach.

It is significant to note that recent experimental engines (ramjets as well as turbojets) are, in the main, constructed of conventional alloys and are provided with rather elaborate means of external cooling. This may serve to emphasise that available materials have become such a critical metallurgical problem that a point has been reached where engineering design improvements have become mandatory, particularly when it is fully appreciated that standards of design may change entirely with increase in operational temperatures, and that the indiscriminate specification of super-alloys may not only be useless and wasteful, but may actually result in the production of less satisfactory parts.

Despite optimistic predictions by some sources, it is unlikely that alloy development can keep pace with the engine designers' rapidly increasing demands for materials which will

withstand higher and higher temperatures. These demands are perhaps justifiable in many respects, for the efficiency of the gas turbine or other jet power plant is dependent largely upon the temperatures at which specific components operate. It has been asserted that an increase of 100° F. in operating temperature may improve thermal efficiency as much as 30 pct., and therefore in future designs, external cooling of specific parts will not be tolerated, and does not in itself constitute a satisfactory solution to the extant problems which is resolved into one of temperature differential and not temperature level.

Particular emphasis may be placed on this observation when the adverse effects of flame-tube warpage on combustion efficiency are considered. It has been stated that flame tubes do not operate at uniform temperature, that they must resist scaling, distortion, cracking and fatigue effects, and that they must be light in weight, a combination of factors difficult to obtain in a single material.

Therefore, the solution to this and directly related problems of warpage, distortion, etc., encountered in tail pipes, cones and other sheet-metal parts for high-temperature service appears to rest with initial design providing for maximum uniformity of heat application and the augmentation of such design with materials capable of distributing unavoidably localised heat before prohibitively high temperatures are reached at points of heat impingement, thereby avoiding destructive thermal stress gradients without diminution of thermal efficiency.

The inadequacies of the more common laboratory tests (stress-rupture, creep, etc.), in accurately and completely evaluating materials, particularly those in sheet form, for service over wide extremes of temperature have emphasised the necessity of testing under conditions simulating those encountered in actual service.

Tests were made on a wide range of stainless and heat-resisting steels and alloys. Some of these were plated with high-conductivity materials such as

copper, with an additional coating of nickel or chromium for protection. In addition, tests were also made on various clad materials, in which a high-conductivity pure metal was clad with a heat-resisting material. Tubular test specimens, 2 in. ID × 5 in. in length (fabricated by forming and spot-welding of the various sheet alloys) were mounted on rotating spindles (1 r.p.m.), while localised heating 1½ in. from one end was effected by radial oxygen/natural gas-flame jets impinging upon the inner surface of the tube specimen. Rotation of specimens was found to be an expedient method of avoiding hot spots in the tube wall at each of the eight points of flame impingement. Application of flame and local heating of tubes to approximately 1,500°–2,000° F. in the hottest region (depending upon the thermal conductivity of the particular material in test, but also upon related effects of emissivity, radiation losses, reflectivity, etc.), continued for a period of 5 min., and was followed by cooling for 1 min. in still air.

Flame-tip temperatures recorded periodically during the test programme were shown to be remarkably constant for a given pressure and valve setting of oxygen and natural gas supply. The test cycle, including one heating and one cooling phase, was fully controlled and was automatically repeated until the first visible indication of circumferential cracking was noted.

During the initial stages of impingement testing, several interesting observations with regard to the behaviour of the various materials were made. Visibly wide variations in distribution of temperature along the length of tubular specimens made it apparent that thermal conductivity has a pronounced effect on temperature gradients in specimens of the different alloys. It was noted that the ability of materials to distribute localised heat decreases quite noticeably.

Upon examination of results shown in this investigation, it becomes apparent that severe temperature gradients occurring in sheet-metal assemblies subject to repeated and local applications of heat are the primary source of warpage, buckling and ultimate complete failure by cracking of such components with no load factor other than that imposed by self-support of the assembly. It has been demonstrated that thermal conductivity has a very significant effect upon the development of destructive thermal-stress gradients and that from this standpoint, the use of newer,

current, and proposed high-temperature alloys, inherently of very poor conductivity and high-thermal expansion will result in no significant improvement in resistance to failure of sheet-metal parts under service conditions of non-uniform heating.

These observations, however, detract nothing from other requisites of high-temperature alloys: i.e., sufficient oxidation resistance, low rate of creep and adequate strength characteristics at elevated temperatures; neither is the necessity of development and testing for these properties minimised. It is merely emphasised that properties of thermal conductivity and expansion become of increasingly greater importance in locally heated thin sheet than is commonly realised. Further, relatively insignificant improvement in thermal conductivity will quite substantially inhibit distortion and failure by diminution of thermal gradients, whereas more appreciable enhancement of other properties, such as high-temperature strength, oxidation and creep resistance, expansion, etc., will be required to produce an equivalent effect in prolonging the service life of sheet metals under local impingement by flame and/or hot gases.

In observing the mechanism by which sheet metals warp and crack under repeated local heat application it is indicated that initially, local expansion takes place causing deformation, displacement, and upsetting in areas of highest temperature due to restrictive and opposing force of surrounding cooler metal. Upon subsequent cooling, stresses imposed upon displaced metal by contraction of a greater volume of surrounding (cooler) metal may be of sufficient magnitude to cause rupture. Alternate heating and cooling of local areas aggravate this effect by introducing an additional factor of thermal fatigue. It follows then, that more abrupt temperature differentials and greater unit stresses will develop in locally-heated materials of poor conductivity and high-thermal expansion, wherein heat is not efficiently distributed or dissipated and where the amount of deformation (elastic and plastic) is greater for a given temperature.

This has been reflected in the behaviour of materials tested in the present investigation in that the direct relation between length of test life and thermal conductivity is particularly pronounced. In addition, it has been noted that for a given number of test cycles, substantially less warpage and

other distortion occurs in tubular specimens of high conductivity and/or of low expansion. The general improvement in test life of heavier-gauge materials is directly ascribed to effective increase in thermal conductivity of tube walls.

It is obvious that such materials as type 430 stainless steel (ferritic), aluminium coated low-carbon steel, copper sheet, and others cannot reasonably be specified in applications where any benefit of their properties of relatively high conductivity and low expansion are more than offset by deficiencies attending their service at temperatures in excess of those causing rapid oxidation, scaling or serious impairment of strength characteristics. With specific reference to improvements in thermal conductivity by application of electro-deposited coatings, it appears that slight benefits realised in some instances may be due to effective increase in thickness of material, and therefore in conductivity, and not particularly to benefits derived directly from superlative conductivity of coating metals. The lack of adequate initial adhesion, predilections toward oxidation, blistering, and scaling, wide differences in thermal expansion between base and plated layers, requirements of inordinately heavy (and protected) coatings, and other limitations of the electroplating process would seem to make very unlikely any extensive future use of such methods to attain increased thermal conductivity in applications where sheet metals are exposed to unavoidable temperature variations.

Conversely, the clad materials tested in this programme have shown considerable promise in improving characteristics of distortion and extending the life of parts subjected to repeated local flame impingement, and it has become evident that such materials, particularly Inconel-clad copper and very likely stainless-clad copper, may well offer the optimum balance or combination of properties necessary to meet many of the more severe requirements of sheet metals in high-temperature service.

It is anticipated that the application of high-conductivity clad metals to sheet assembly components will not only result in more satisfactory service life of such parts, but in greater overall efficiency of power plants due to the maintenance of critical shape and dimensional tolerance. It may be noted that greater engine efficiency may derive from effective increase in permissible operating temperatures by

virtue of minimised temperature gradients. Future applications of sheet-metal combustion chambers, ducting, etc., in which internal pressures increase to a point where load-carrying capacity becomes requisite, and where problems of thermal fatigue become even more serious than heretofore, may reasonably require clad metals from standpoints of high-temperature strength, oxidation and corrosion resistance, as well as proficiency in distribution of localised heat. In addition, the use of lighter insulating blankets and supporting members may logically be made possible in assemblies where severe local hot spots do not occur. Over and above the foregoing considerations and obvious economic advantages, the utilisation of clad metals may be found to be an expedient conservation measure during periods of critical alloy shortages.

Bronze Welding or Fusion Welding for Repairing Cast Iron

By H. B. Gilson

BOTH fusion welding and bronze welding can be used for the repair of broken iron castings. In order to determine which method should be used in a particular case it is necessary to understand the basic differences between the two methods.

In bronze welding, the casting is not melted. Except on the line of the weld, which is heated to about 550° C., the casting is usually heated to a temperature between 300° C. and 425° C. Because the temperature is so low, only local preheating is usually needed. Expansion and contraction stresses will not cause trouble.

In fusion welding, the prepared bevelled edges melt and the vee is filled with molten metal from a cast-iron welding rod. A temperature of the order of 1,200° C. is required to melt the casting along the line of the weld and, because of this high temperature, the rest of the casting is usually preheated to 550°–650° C. in order to prevent the setting up of stresses which might crack the casting later. In fusion welding, the weld metal has approximately the same colour, composition and machining characteristics as the original part.

Whether bronze welding or fusion welding is used, the joints are prepared by bevelling the edges to form a 90° vee. After either welding operation, large parts must be covered with asbestos sheets to protect them from draughts ; small castings may be buried in sand, lime, ashes or other insulating material.

The first step in selecting the proper welding method is to identify the type of iron—grey, white or malleable. Welds in white iron are not usually satisfactory. Unless the part is specially treated after welding, it will lose its wear resistance at the weld. This type of casting is not usually encountered ; when it is, use fusion welding.

For grey iron castings, either method can be used, the need for a colour match and the temperature at which the part will be used will influence the choice. For castings which will be heated to temperatures above 250° C., bronze welding is unsatisfactory due to the filler metal losing strength above this temperature.

Fusion welding is the best method of repairing " poisoned " castings, such as oil-soaked machinery and brine-soaked castings, and for castings which have to be machined, tapped, threaded or enamelled.

In fusion welding the entire part should be preheated in a furnace. Otherwise the high temperature at the weld zone, and the low temperature of the rest of the casting will set up stresses and cause new cracks. Whenever it is impossible to build a furnace, the blowpipe can be used for local preheating and the job done by bronze welding.

Bronze welding should always be used on malleable castings[1] as the heat of fusion welding would destroy the malleability, near the weld, and make the casting brittle in that region.

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1 American malleable castings are blackheart.

Mercury-Balance Method for the Measurement of Gel Strength

AN improved method for more precise measurements of the tensile strength of gels has been developed by W. J. Hamer, of the National Bureau of Standards. This procedure, which gives the strength or " yield value " and resistance to deformation of the material under study, essentially involves the determination of the shearing force necessary to fracture the gel as given by the weight of mercury required to pull a standard disc from the gel in which it is imbedded.

In several of the applications of gelatin, glue, starch, agar, and various gums, it is important to know the tensile strength of the gel or jelly. This property was originally measured by comparison with a set of arbitrary standards on the basis of the resistance offered by the gel to finger pressure. Although such a procedure was undoubtedly satisfactory for many commercial purposes, there was need for a more objective method. Such a method is very important, for example, in studies of gelatin jellies for use in photographic operations, particularly with the increasing use of flexible film supports instead of rigid glass bases.

Although the procedure was designed specifically for the study of the paste walls of dry cells, it may be applied to all types of gels and used in the study of food starches, in following small changes in starch pastes for use in adhesives, and in many other applications.

The method involves the balancing of the cohesive forces of the gel against a gradually increasing quantity of mercury until the yield point is reached and the gel is broken. A brass disc suspended in a beaker containing the gel by means of a wire attached to one beam of an analytical balance. An adjustable platform over the balance pans supports the beaker. The gel is covered with liquid petroleum to prevent " skin " formation. Mercury is added from a burette at a constant rate to a container on the other pan. Different flow rates are made possible by use of a removable capillary tip held to the burette by a rubber tube. The capillary tip is calibrated before use by weighing the mercury it delivers in a given time. As the mercury is added, the height of the platform is changed manually, so that the pointer of the balance is always kept at zero. A vertical scale indicating the height

of the adjustable platform is read at frequent regular intervals until the gel is broken.

The weight of mercury required to produce a fracture in the gel, divided by the area of the brass disc gives the gel strength in grams per square centimeter. The rate of change in height of the adjustable platform gives an indication of the resistance the gel offers to deformation. A fast rate means that the gel is easily deformed, whereas a slow rate indicates that the gel resists deformation and is probably quite rigid. Although rigid gels usually offer high resistance to deformation, this is not always true.

This method has a precision greater than 0·5%. Its limitations lie more in the reproducibility with which gels can be prepared than in errors inherent in the method. It may be applied to all types of gels, whether they are of the reversible (gelatin) or irreversible (starch) type.

Investigation of the Corrosion of Cast Irons by Molten Aluminium and Aluminium-Silicon Alloys

By P. Bastion and S. Daeschner

THE investigation was carried out with a view to determining the best cast-iron composition for melting crucibles. Specimens tested included two grey cast irons, a malleable cast iron, cast irons with 6% and 32% chromium and cast irons with 1% and 2·5% molybdenum, and finally a wrought mild steel. These were tested by immersion for 1 and 8 hours in a quiescent melt of super-purity aluminium (99·995%) and of aluminium-silicon alloys (11·57% Si and 15·92% Si, respectively), maintained at temperatures of 800° and 850° C. The extent of the attack was determined by the loss in weight of the specimens, the aluminium adhering to the surface after immersion being dissolved away in caustic soda. An alternative method was to determine the iron taken up by the melt.

The results show that, with the exception of the malleable cast iron, specimens were attacked more severely in the aluminium—11·57% silicon and particularly in the aluminium—15·92% silicon alloy than in the pure molten aluminium. In contact with pure aluminium the grey cast iron with 3·55% carbon was the best, being followed by the grey cast iron with 3·31% C, the 6% Cr iron, the malleable iron, the 32% Cr iron and the mild steel, the last two being quite inferior. In contact with the aluminium-silicon alloys the malleable cast iron proved to be superior, especially so in the alloy with the higher silicon content. The 3·55% C and 3·31% C irons came next in that order, followed by the 6% Cr iron, the mild steel and the 32% Cr iron.

The mechanism of the attack of the specimens by the molten aluminium and aluminium alloys was deduced from microscopic examination of the attacked specimens, the observations being interpreted in the light of the equilibrium diagrams concerned (Al-Fe, Al-Fe-Si and Al-Fe-Cr).

In the case of the mild steel, diffusion was found to occur in both directions—i.e., iron towards aluminium and aluminium into the iron. The diffusion of the aluminium into the iron results in the suppression of the γ-phase region and of the possibility of the formation of pearlite.

In all the other cases the rate of solution of the iron in the aluminium is much greater than the very small extent of diffusion of the aluminium into the iron. The rate of solution is increased by the rise in temperature and by the presence of silicon. A layer of $FeAl_3$ is formed. As carbon is unable to enter the $FeAl_3$ layer an increase in the carbon content and formation of pearlite occurs in the adjoining zone of the specimen leading to the formation of pearlite. The presence of pearlite, particularly where the latter forms a continuous layer, favours the resistance of the iron to attack by molten aluminium. Differences in the behaviour of the grey and malleable cast irons suggest that, in addition to the carbon content as such, the form in which the graphite is present also has an effect on the behaviour of the iron.

Pressure Blast Furnace
By B. S. Old and E. R. Poor

EXPERIMENTS consisting of operating a blast furnace at higher-than-normal top pressures, as proposed by Arthur D. Little, Inc., were carried out by the Republic Steel Corporation initially during World War II and much more extensively during the past twenty months. The results of the Republic trials indicate that pressure blowing is a solution to the problem of increasing pig-iron capacity without necessitating major changes to existing equipment.

If the top pressure in a blast furnace is increased by throttling exhaust gases, the result is an increase in the average static pressure through the furnace, which decreases the volume and increases the density of the gases passing through the stack. Thus it is possible to blow a greater-than-normal amount of wind through the furnace before a critical gas velocity is reached, above which furnace operation is impractical because of excessive flue-dust production, slipping, and channeling. Since iron production varies directly with wind volume blown, an increase in the average static pressure, which makes possible increasing the amount of wind blown, results in an increase in the tons of iron produced. By blowing large volumes of wind at lower-than-normal gas velocities, a more uniform pattern of gas flow in the working volume of the blast-furnace results, and, in addition, there is longer time for contact between reducing gas and ore. In other words, the gas is used more efficiently, thus enabling the furnace to carry a higher burden ratio which is reflected in a lower ratio of carbon monoxide to carbon dioxide in the top gas.

Results of the experiments by the Republic Steel Corporation are said to have confirmed the theories of pressure operation, in that, iron production has been increased 11–20% per day with a 13% decrease in coke rate per ton of pig and a 30% reduction in flue-dust production. A manufacturing cost saving of more than $1 per ton of iron has been realised. These results are being obtained while operating at an average top pressure of approximately 10 psi. Turboblowers will soon be

delivered which will make possible the operation of a blast furnace at 20 psi top pressure. Calculations indicate that results at this higher pressure should be even more startling when compared to normal operating production and cost figures. One new blower which was to be delivered to the Warren plant of Republic in April or May was of 125,000 cfm, 40 psi capacity, the largest blast-furnace blower in the world.

Although initial trials were hampered by minor mechanical difficulties, new devices, occasional alterations, and general experience have eliminated any problems peculiar to pressure operation.

No major changes in the design of a modern blast-furnace plant are said to be necessary to permit pressure operation. The minor alterations consist of the installation of a throttling valve to regulate pressure, a clean-gas system for equalising furnace top pressure with the hopper pressure when dumping the big bell, and a one-piece hopper and hard surfacing for both bell and hopper seats. The new devices are either equipped with new mechanical-operating controls or are tied into existing systems, and once installed, require little attention and low maintenance. No additional personnel are required to operate a pressure furnace. One of the major features of this new method of operation is the relatively small financial outlay necessary to convert a modern plant to pressure operation.

Out of a total of 245 furnaces now in blast in this country, approximately 80 or 32·6% could be converted to permit operation at 10-psi top pressure with existing blowing facilities. This estimate is based on present blowing equipment as estimated in the Iron and Steel Works Directory for 1945 and on information obtained from turboblower manufacturers regarding their recent installations. It has been assumed that a blast-furnace plant equipped with 30-psi blowers of adequate capacity can be operated at approximately 10-psi top pressure. Regardless of the fact that some furnaces might not have the maximum wind capacity required, it would still be advantageous to convert because, although maximum iron-tonnage increases would not be realised, coke saving, less flue-dust production, and smoother operation would result.

In addition to the iron blast furnace, it appears that the principles of pressure blowing may be applied to non-ferrous-metal smelting, as carried out

in the copper or lead blast furnace. Development of a suitable means of charging the furnace under pressure to replace the existing pusher and raised-door method seems the only major alteration necessary.

Hot Tearing of Aluminium Alloy Castings
By A. A. Bochvar and Z. A. Sviderskaya

AN investigation involving a quantitative test for hot tearing was carried out to determine the resistance to cracking during the recrystallisation period of cast specimens of aluminium-copper alloys containing 0–12% copper and of aluminium-silicon alloys containing 0–4% silicon. The test method involved the use of a mould having one of its two ends movable. As shrinkage stresses caused the casting to contract it was forced to lift a weight attached to the movable end. The weight was varied to determine the resistance to shrinkage stresses of a given alloy.

Aluminium of 99·98% purity was found to have a critical stress of 58g./sq. mm., and for various percentages of copper in aluminium, the critical stresses were: 1%, 26; 2%,

less than 2; 3%, 8; 5%, 12; 8%, 18; 10%, 82; and 12%, greater than 120. For various percentages of silicon in aluminium the critical stresses were: 0·1%, 46; 0·2%, 22; 0·3%, less than 2; 0·5%, less than 2; 1%, 2; 1·5%, 6; 2%, 6; 2·5%, 26; 3%, 98; and 4%, greater than 120. Qualitative tests showed that the 0·5% silicon alloy has the lowest value of critical stress.

These results were explained on the basis that the tendency to hot tearing increases proportionally as the " effective temperature interval " of crystallisation up to the concentration at which eutectic forms on non-equilibrium cooling. It is suggested that small quantities of eutectic heal cracks that form in the early part of the cooling process, and therefore hot tearing decreases fairly rapidly with the appearance of eutectic.

Conditions for the Annealing of Pure Al-Mg Alloys for Decorative Purposes
By J. Herenguel and M. Scheidecker

IT is known that the best results from electrolytic brightening and anodising are obtained when high-purity aluminium is used. High-purity aluminium, however, has the disadvantage of very low mechanical properties, and being self-annealing at room temperature is incapable of being hardened by working. The use of super-purity aluminium as a cladding on a stronger aluminium-alloy sheet base constitutes only a partial solution of the problem.

To meet the demand for an aluminium-base material capable of being electrolytically brightened, anodised and used for decorative purposes, while at the same time possessing adequate mechanical strength, the authors have developed two Al-Mg alloys made from high-purity materials and referred to as " Brillalumag 3 " and " Brillalumag 5 " with magnesium contents of 3 and 5%, respectively.

The alloys used for the experiments

described in the present article were prepared from 99·99% aluminium and 99·95% magnesium, melted in graphite crucibles, homogenised in the as-cast condition and then subjected to hot- and cold-rolling. The experiments were intended to determine the optimum conditions of cold-working (rolling) and annealing in which the formation of a large grain size—undesirable where the metal is to be electro-brightened and anodised—could be avoided.

The results obtained show that in order to avoid coarse grain in the recrystallised alloys, cold deformations less than 25% are inadmissible and deformations less than 50% are preferably avoided. Deformations greater than 300% tend to cause orientation of the recrystallised grains and should also be avoided. The annealing temperature should lie between 350° and 425°. Heating to the annealing temperature should be rapid. Slow cooling after annealing of the alloy with 5% Mg is undesirable.

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